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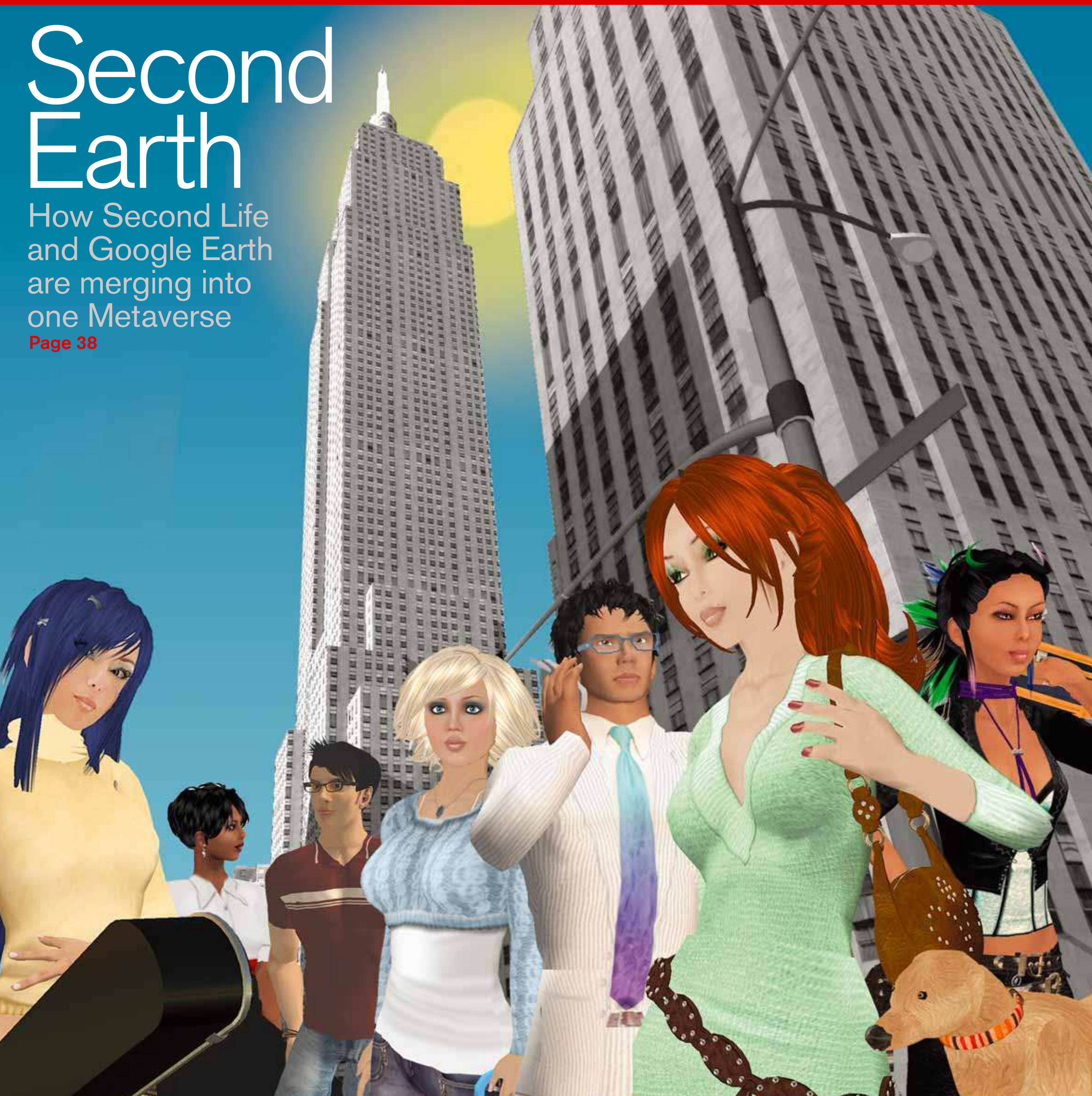
Second Earth

How Second Life and Google Earth are merging into one Metaverse
Page 38

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Contents

Volume 110, Number 4

Cover: Buildings modeled by REVI21ON visualization; Second Life avatars styled by Iris Ophelia

What's New on Our Website

technologyreview.com/secondearth

For an entirely different perspective on this issue's cover story about the coming era of 3-D interaction on the Internet *("Second Earth," p. 38)*, read the "director's cut" version online. Immersive, computer-generated 3-D

environments such as Second Life and Google Earth are opening up new ways to work, socialize, and manage the real environment—but there's only so much we can do on the printed page to bring these worlds to life. So we've added content online, including links that will take you directly to most of the spots mentioned in the story (assuming you've downloaded the necessary software to your PC).

technologyreview.com/holland

David Talbot's feature on engineering measures taken by the Netherlands to prepare for the effects of climate change describes a new way of thinking about disaster prevention

("Saving Holland," p. 50). Online, we show a computer-generated depiction of how Rotterdam would flood if certain dikes broke and an animation of how the Netherlands' new floating houses behave during a flood.

technologyreview.com/wii

This month's Hack features the Nintendo Wii game console *(p. 22)*,

which is making a splash because of its advanced controllers. Online, we dissect the Wii. And within a Web-based player, we let readers test their mettle in a virtual bowling alley, courtesy of Nintendo's game designers!

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DRONES THAT NAVIGATE INDEPENDENTLY

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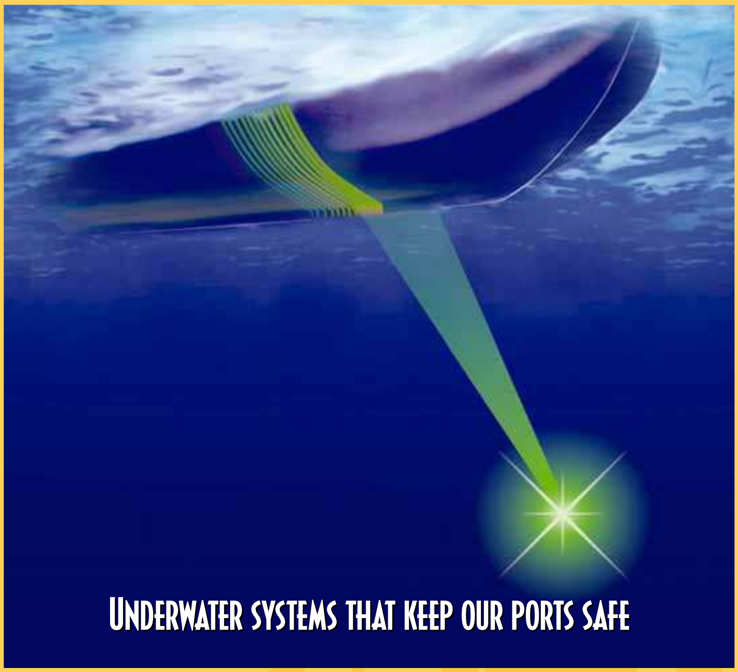
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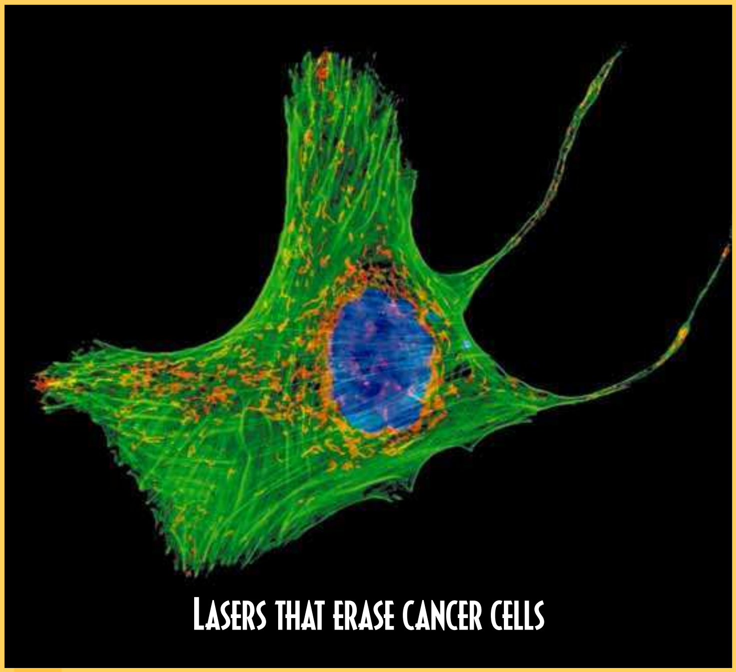
LASERS THAT ERASE CANCER CELLS

Contributors

Wade Roush is a freelance writer and the former West Coast bureau chief for *Technology Review*. As he researched this issue's cover story about the coming of the 3-D Internet *("Second Earth," p. 38)*, he says, he was unprepared to meet so many people who had read Neal Stephenson's 1992 cyberpunk classic *Snow Crash* and were busy creating their own versions of the "Metaverse" depicted in the novel. "The founders of 3-D virtual worlds like Second Life, There, and Google Earth have always said that *Snow Crash* was part of their inspiration," says Roush. "But I didn't expect that so many of their customers would also be versed in science fiction lore about life 'inside the computer'—or, even more remarkably, that they would be taking the technology into their own hands and building whole virtual cities and societies, some mirroring the real world, some not."

Roush has degrees in the history of science and technology from Harvard University and MIT. His writing has appeared in *Science*, *The Encyclopaedia Britannica*, *IEEE Spectrum*, and *Technology and Culture*.

David Gelernter, a professor of computer science at Yale University and a noted figure in artificial intelligence, is a dissenting voice in his field. In this issue, he explains why *("Artificial Intelligence Is Lost in the Woods," p. 62)*. "This piece was a big occasion for me," he says, "because it was a chance to treat two topics in AI and philosophy of mind that are closely related but not usually discussed together. I argue that contrary to what cognitivists have long argued, the conscious mind is *not* like software running on a computer. As far as we can see today, that analogy is simply wrong. On the other hand, I've also developed a 'positive' view—a comprehensive but simple view of how thinking works. People tend to ask me to deliver the negative blast or the positive theory, but not both—though of course they're two facets of one topic. This piece is a rare occasion to put them together."

Gelernter is a national fellow at the American Enterprise Institute and a senior fellow in Jewish thought at the Shalem Center in Jerusalem. His writing has appeared in many magazines and newspapers. He is the author of, among other books, *Mirror Worlds*.

David Ewing Duncan, a contributing editor for *Technology Review*, explored his interest in scientific efforts to improve alertness by briefly undergoing two treatments: his frontal lobe was electrically stimulated, and he took the pill Provigil, which is prescribed for people suffering from narcolepsy and other sleep disorders *("Brain Boosters," p. 77)*. "In wanting to test brain boosters on myself, I had my curiosity win out over my fears," he says. "What if I became addicted to these mild stimulants of my frontal lobe? What if the boosters somehow fried my brain and I became a blithering idiot? But what if they worked, and I became that much more cognitively attuned? Also, I was curious about how effective these brain boosts are—and about how far society should pursue them."

Duncan is the author of the forthcoming *Experimental Man: A Molecular Autobiography* as well as chief correspondent for public radio's *Biotech Nation*.

Bryant Urstadt reviewed a new service called Clear, which allows airline travelers to whisk through security at a few U.S. airport terminals *("Iris Scanning, Now at JFK," p. 72)*. The catch is that Clear and other "registered traveler" programs depend on the use of a "terrorist database" kept by the U.S. Transportation Security Administration. "The balance between freedom and safety is one of the most important problems the U.S. faces" says Urstadt. "Technology is adding new options and trade-offs and obviating others."

"On a side note," he adds, "I was interested to learn more about Clear's founder, Steven Brill. He published his first editorial in the *New York Times* when he was about 19 and wrote speeches for the presidential campaign of John Lindsay while at Yale Law School. He founded *The American Lawyer*, Court TV, and *Brill's Content* and wrote a book on American bureaucracy after September 11, called *After*, which led him to the security business." Urstadt has written for *Harper's* and *Outside*.

Eric Joyner painted *The Collator (p. 63)* to accompany David Gelernter's essay about artificial intelligence. The 18-by-24-inch oil-on-wood painting depicts a robot engaged in what Gelernter says a machine will never experience: conscious thought. "This painting," says Joyner, "represents one of my typical robots striking the pose made so popular by Auguste Rodin in *The Thinker*."

Robots & Donuts: The Art of Eric Joyner will be published by Dark Horse in October.

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On Good Design

Your design issue made for enjoyable reading, although in your cover story on Helio's Ocean phone, you fell under the spell of Helio's marketing ("Soul of a New Mobile Machine," May/June 2007). Helio sacrificed the defining feature of a desirable portable communication device—slimness—for the dubious benefit of rounded "pill" corners. There is good reason why size reduction has always been the holy grail of cell-phone manufacturers: smaller is better. But instead of working toward slimness, Helio painted Ocean black and put a silver girdle around it to make it *look* thin. This does not make it any easier to carry in a shirt or pant pocket. The Ocean is the antithesis of good design. Contrast that with Apple's "Snow White" design language, as described in the same issue ("Different"). Apple's decision to use perpendicular sides on its machines led to savings in plastic, packaging material, and shipping costs.

What's more, Ocean is opening stores in the most expensive retail locations in the country and providing "spa treatments" for phones. This is a return to the excesses of the tech bubble. No wonder Helio has burned through much of its $440 million in funding and lost $192 million last year.

Chris Cole
Redwood City, CA

In reading your design issue, I thought of a part of a verse about the Venus de Milo from "The Engineer's Drinking Song": "On seeing that she had no clothes, an engineer discoursed/'Why, the damn thing's only concrete, and should be reinforced!'"

Design is often very mysterious to technologists. To some, it means a visual appeal that so far has resisted adequate explanation. To others, functionality, simplicity, use of materials, or cost tug at the heart. For many of us, straight lines and right angles form the foundation of design, from buildings to chips. The expanded possibilities for more-complex shapes often confuse the engineering soul.

Our appreciation of design rests in the fact that we're equipped with senses that have evolved in nature, not in sheetrock boxes, on asphalt roadways, or in front of luminous screens. We best appreciate that which we can recognize with hand or eye, and for which we are prepared by our wiring. The woods around my home are "designed" just for me; some lousy Microsoft application obviously is not.

So I hope that you or I might see Venus as a woman, rather than a structurally inadequate and otherwise meaningless obstruction in an otherwise acceptable rectilinear box.

Richard Stein
South Norwalk, CT

I enjoyed Jason Pontin's most recent editor's letter ("On Beautiful Machines," May/June 2007). He is right: machines should be simple. A decade ago I bought a 1996 Buick Century, and in 2001 I bought a new one. When I put the shifting lever into drive in the 1996 car, I could clearly see the pointer in sunlight striking it from any angle. But my luxurious 2001 Buick doesn't have a pointer; it has a small lit-up orange square that moves across a screen of letters when you move the shift lever. I found this change impressive until I put my car into drive one late afternoon when the sun hung low in the sky. I couldn't see the orange square. I had to block the sunlight with my left hand to find drive. Some improvement.

Donald Morse
Gray, ME

The Semantic Web

We read with interest John Borland's piece on the Semantic Web ("A Smarter Web," March/April 2007). We agree that this is an exciting time in the Semantic Web's development, yet we want to point out that its great degree of structure has drawbacks. As the article noted, Semantic Web users must learn complex ontology languages and structure their information and data using them. This difficulty inhibits the growth of the Semantic Web. It is thus arguable whether the Semantic Web can approach the scale of the standard Web, where anyone can easily create and publish content.

Ideally, we should combine the strengths of the Semantic Web and the normal Web. Search would be a good place to start. Today, global free-text search is the primary means of querying the whole Web, but it provides only coarse-grained access to documents. In contrast, the Semantic Web allows much more precise queries across multiple information sources (say, querying for a particular attribute, such as "street address"). However, it is on a much smaller scale, involving far fewer documents. We could imagine combining normal and Semantic Web queries—for instance, to search the free text of all real-estate Web pages written by women in Boston during the last week for the word "Jacuzzi." Taking this further, the few structured relationships currently in the Semantic Web could be used to refine the results of mainstream search engines.

Finally, as so much activity in the life sciences is focused on large-scale interoperation on the Web (as found in drug discovery), we feel that biological research could serve as a useful guide and driving force for the development of Web 3.0.

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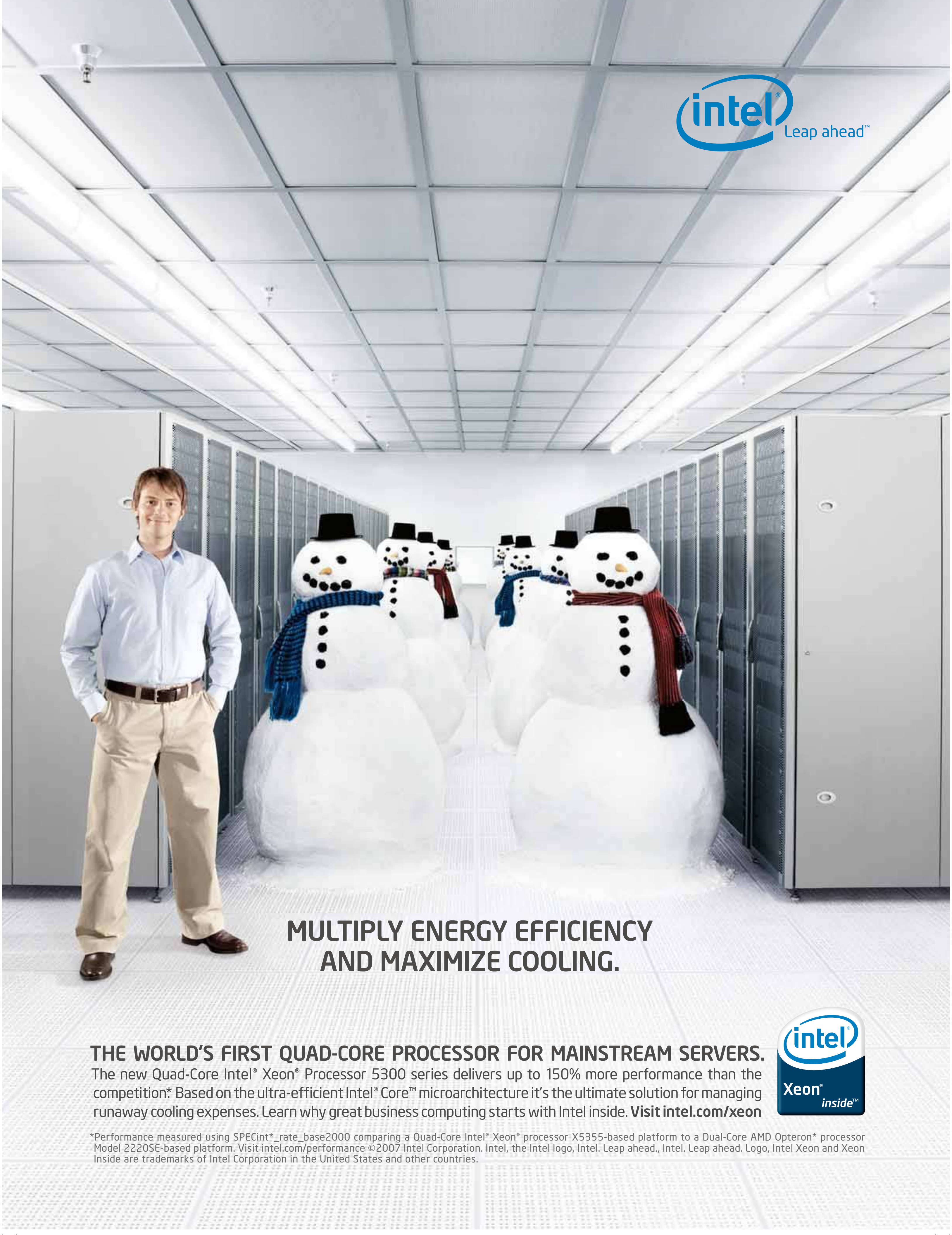
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A Virtually New Web

The collision of virtual reality and mapping brings excitement to cyberspace

As I write, my meat is earthbound in Tanzania, at the Technology, Entertainment, Design (TED) Global 2007 conference, but my avatar, Xan Hazlitt—pictured above—freely roams the virtual world of Second Life.

Like many technologists my age, I first encountered the idea of virtual worlds in William Gibson's 1984 classic of "cyberpunk" science fiction, *Neuromancer.* I was at boarding school in England, and it was an *exeat* weekend (that is, vacation). The British boys had gone home to their families, and the foreign students were marooned in the school's houses. But I was neither homesick nor lonely, because on the previous day the school's bookshop had delivered a brand-new, hardbound copy of Gibson's novel.

I remember my excitement when I read how Case, a "cowboy" or criminal hacker, jacked into the matrix after a long, chemically imposed exile from cyberspace, his "distanceless home": "Inner eye opening to the stepped scarlet pyramid of the Eastern Seaboard Fission Authority burning beyond the green cubes of Mitsubishi Bank of America, and high and very far away he saw the spiral arms of military systems, forever beyond his reach."

Wow! I thought. Now *that* was poetry!

My interest in what Gibson memorably called the "consensual hallucination" of cyberspace was inflamed by two later books: Neal Stephenson's 1992 cyberpunk novel *Snow Crash* and David Gelernter's 1991 *Mirror Worlds: Or the Day Software Puts the Universe in a Shoebox … How It Will Happen and What It Will Mean*. (Gelernter, a professor of computer science at Yale University, writes in this month's essay about why he believes humans will never build a fully conscious artificial intelligence; see page 62.)

In fact, the cyberpunks and Gelernter were imagining two related phenomena. The first is that of the virtual world, a shared, 3-D environment where people and organizations communicate—an environment that is related to our own world but is fictive. By contrast, Gelernter's term "mirror worlds" conveyed the idea of geographically accurate software models of real terrestrial places.

My juvenile enthusiasm for virtual and mirror worlds was shared by the pioneers of the Internet. Almost all early descriptions of the Net make some appeal to the glamour of a social, 3-D cyberspace. And yet until recently, neither virtual worlds nor mirror worlds existed outside the heated imagination of science fiction writers and futurists.

For years, attempts to create virtual and mirror worlds were frustrated. When I was the editor of *Red Herring* magazine in the 1990s, we promoted a new standard called the virtual-reality markup language that was to have given programmers and website designers the means to bring a third dimension to the Internet. ("VRML: The LSD of the Internet!" the May 1996 cover of *Red Herring* exclaimed.) But nothing came of such early technologies.

Today, the virtual world of Linden Lab's Second Life, which was launched in 2003, has seven million registered users, 30,000 to 40,000 of whom are online at any one time. The mirror world Google Earth, which is only two years old, has been downloaded 250 *million* times.

Mere numbers, however, do not convey the beauty, richness, and social complexity of today's virtual and mirror worlds. Nearly everything that human beings can do, they do in Second Life. Dozens of companies, including IBM and Sony Ericsson, are doing business there. And Google Earth has become much more than a hawk's-eye view of the globe. Call up any spot where humans live, and the visitor to the mirror world will see a multitude of layers of interesting or useful information. Second Life and Google Earth have many of the features of Gibson's matrix.

So what changed? First, technology. Most computer users now have the graphics cards and broadband connections necessary to explore virtual and mirror worlds. Storage and processing have become cheap enough to let companies readily purchase the servers necessary to render virtual and mirror worlds in complex detail.

But there's another, more interesting explanation for the growth of Second Life and Google Earth: the companies that created them understood that virtual and mirror worlds are social environments. The most important function of such worlds is communication and personal expression. Therefore, Linden Lab and Google gave control to users, preserving for themselves only the godlike task of maintaining their universes. Second Life avatars can build whatever buildings, clothes, or flora they wish. Anyone willing to learn the open standards of geocomputing can tag information to locations in Google Earth.

In this issue, contributing editor Wade Roush explores how virtual and mirror worlds will merge into what's been called the Metaverse *(see "Second Earth," p. 38)*. The Metaverse, he writes, "will look like the real earth, and it will … [function] as the agora, laboratory, and gateway for almost every type of information-based pursuit." Do you agree? Write and tell me what you think at jason.pontin@technologyreview.com. **Jason Pontin**


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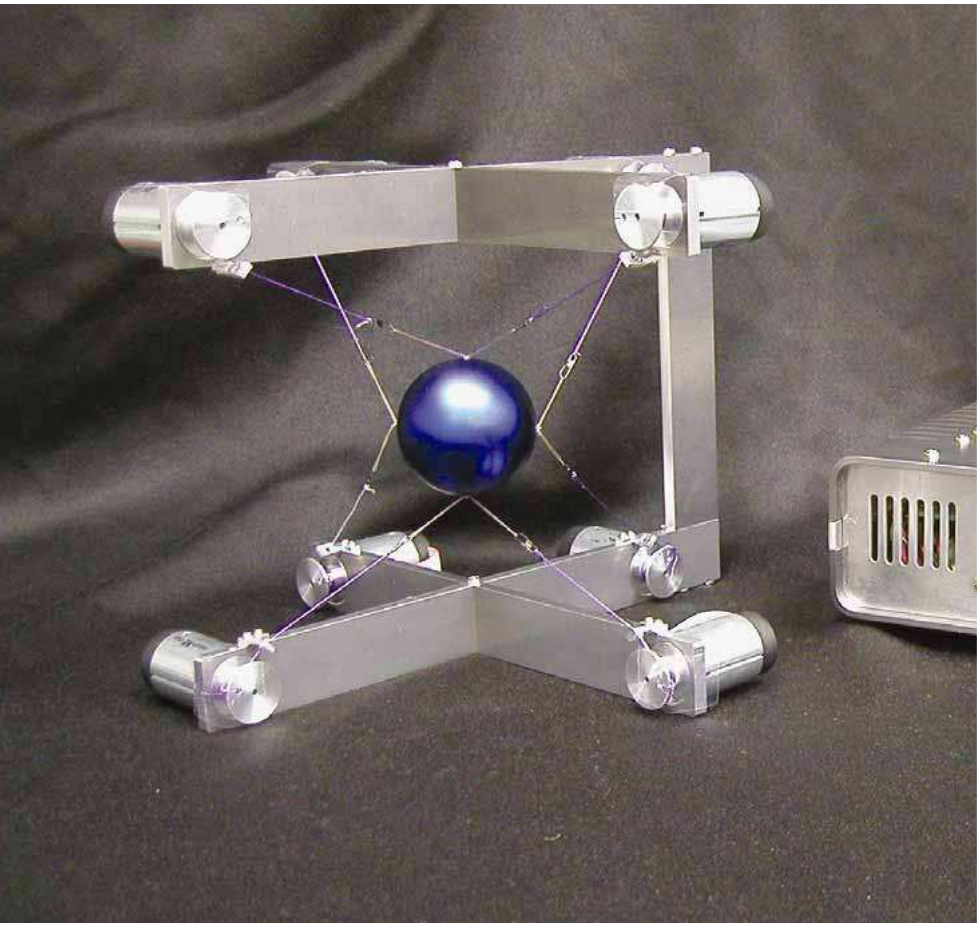


A virtual kayaker views a river (above), while oars convey "feel" via a haptic interface (not shown). For virtual fishing, a fishing rod is attached to a sphere on a desktop interface (left) that offers resistance via motorized wires.

COURTESY OF KATSUHITO AKAHANE

HAPTICS

The Feel of Water

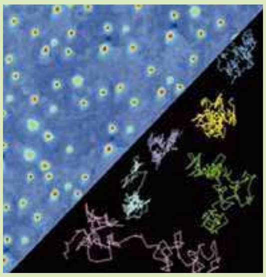
Most research on virtual-touch technology, or haptics, has focused on giving people the sensation that they're feeling solid objects. Now researchers in Japan are developing ways to simulate the subtle feel of flowing water–inching us closer to the day when virtual-reality aficionados can enjoy the sensations of, say, rowing a boat or stirring a drink.

Representing flowing water requires churning through complex formulas that can slow a computer to a crawl. That's a problem for haptics, which uses tactile interfaces to provide physical resistance that simulates the "feel" of actions depicted on a computer screen. "The computation of the force field has to be completed and updated within 1/500 of a second," says Yoshinori Dobashi, an associate professor at Hokkaido University in Japan. "This is almost impossible." Dobashi and colleagues got around this problem by doing some of the math in advance. Working with prototype games that simulate kayaking and fishing, Dobashi and his team created a model that approximates real-world forces associated with different water velocities and different rod or paddle positions. Then they precalculated and saved numerical representations of these forces. During a game, sensations are conveyed to the player via interfaces created by Makoto Sato of the Tokyo Institute of Technology. For example, motor-driven wires pull on the ends of a paddle in the player's hand to simulate kayaking. **Rachel Ross**

MEDICINE

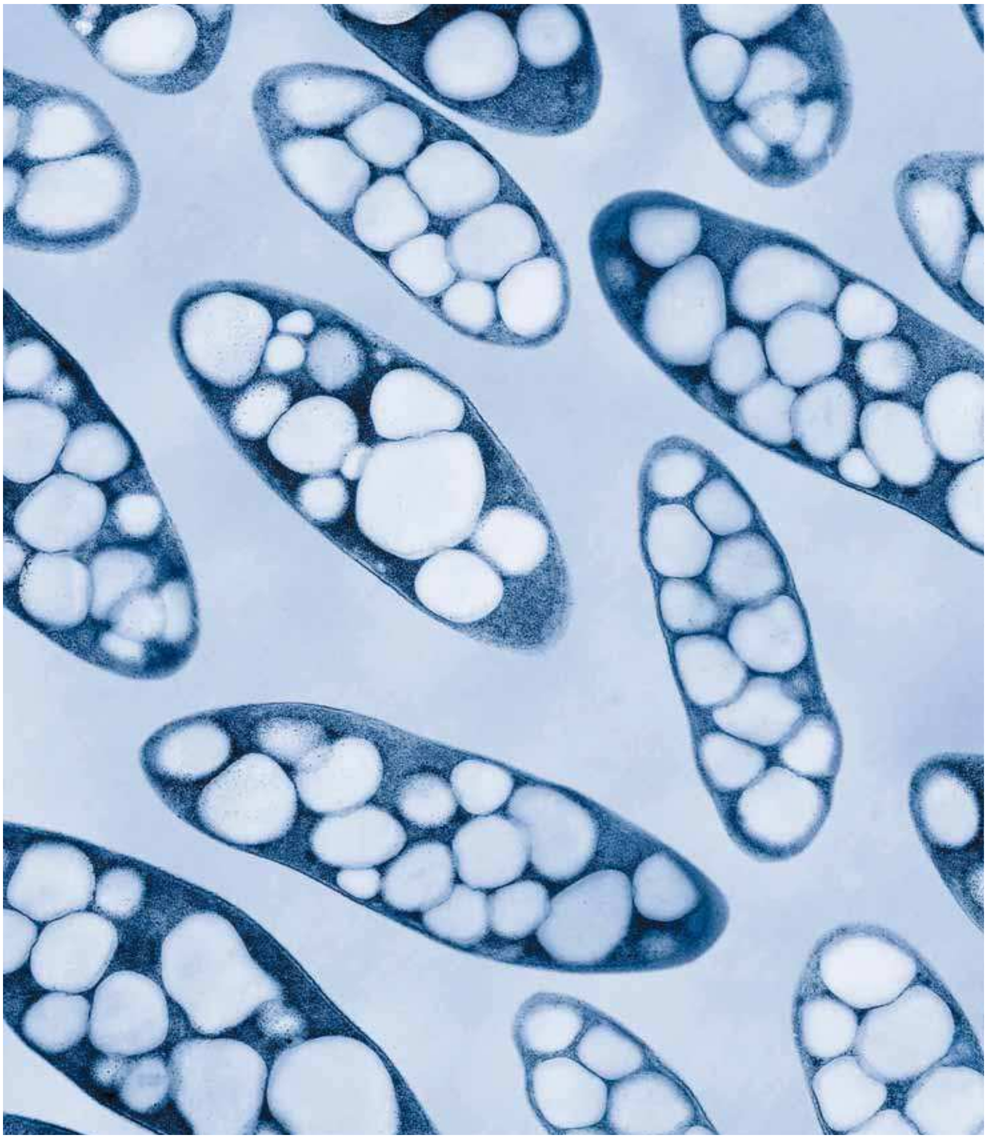
Biolubricant for Arthritic Joints

Researchers at Brown University have discovered that a protein found in the fluid surrounding cartilage acts as a shock absorber, a finding that could lead to better treatments for arthritis. The protein, called lubricin, is found in synovial fluid, a viscous substance inside joints. To learn more about its properties, Gregory Jay, associate professor of emergency medicine and the project's leader, compared two samples of joint fluid: one normal and the other from a person with a rare disease in which the body does not make lubricin. The researchers implanted fluorescent beads



(upper left) in the fluids. Then they used a video camera to track the beads. The tracks *(lower right)* enabled them to calculate the viscosity and other properties of the two fluids. They found that synovial fluid is more effective at protecting joints when lubricin binds to hyaluronate, a salt also found in the fluid. Hyaluronate injections are already used to treat arthritis; the researchers hope that augmenting them with lubricin will boost their protective power, shielding cartilage from damage. Jay's team is preparing a therapy for animal testing.

—Brittany Sauser



COURTESY OF METABOLIX (BIOPLASTIC); COURTESY OF VIRGINIA HOVANESIAN AND JAHN TORRES (ARTHRITIS)

BIOTECH

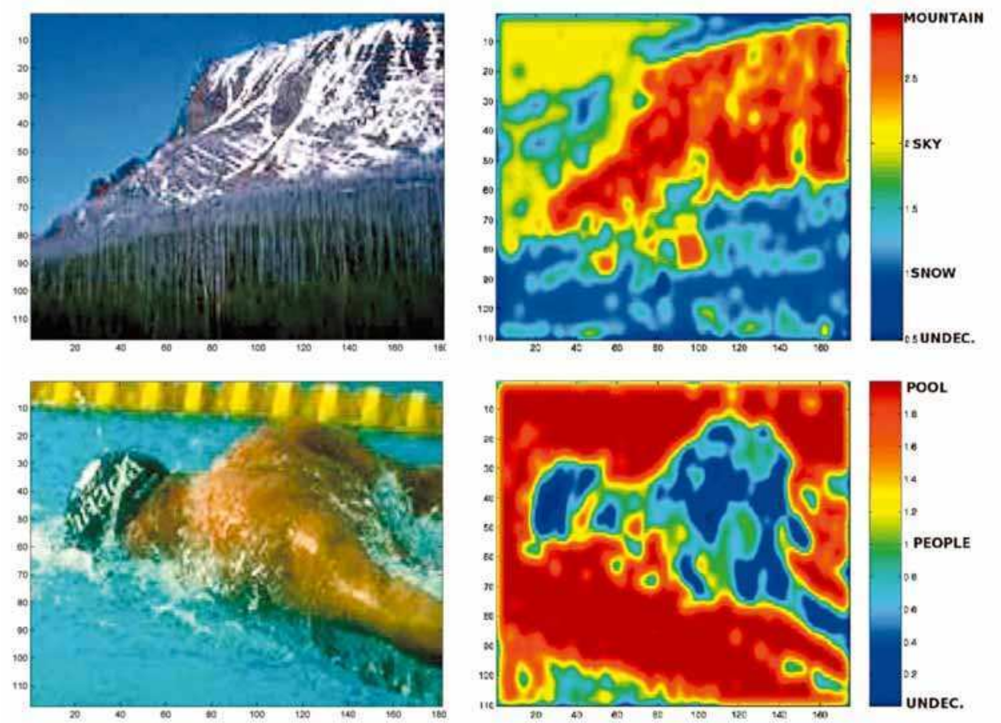
A Bioplastic Goes Commercial

The image above shows genetically engineered bacteria that consume corn sugar and produce a polyester that can be used to make biodegradable plastics, including the types used in shopping bags. (The polyester—called polyhydroxyalkanoate, or PHA—is visible inside the bloated cells.) After years of research and development, the bacteria are almost ready for use on the commercial scale. In a joint venture with Metabolix of Cambridge, MA, which makes the microbes, Archer Daniels Midland is building a plant adjacent to its corn mill in Clinton, IA, that will use them to generate 110 million pounds of PHA annually. The new plant will produce more than 300 times as much PHA as an existing Metabolix pilot plant. "We'll reduce greenhouse-gas emissions by about two-thirds and petroleum usage by about 80 percent compared to traditional petroleum-based plastics," says Metabolix vice president Brian Igoe. And bags made from Metabolix's polymer will degrade even if they drift into wetlands or the ocean. The compound will cost three times as much as petroleum-based polymers. **Peter Fairley**

SEARCH

Finding Images

Searching for images on the Internet can be hit or miss. That's because most image searches rely on metadata (text associated with the images, such as file names or dates), and metadata can be incomplete–if it's there at all. Software that analyzes the images themselves has been notoriously unreliable. But it could get a boost from a technology developed at the University of California, San Diego.



The technology is based on existing systems that learn to describe pictured objects in terms of features like color, texture, and lines by practicing on pictures in a database of known objects. The UCSD system adds a new twist: it assigns each image a likelihood of belonging to categories such as "sky," "mountain," or "people." Then it uses those words to label parts of the pictures. The technique is 40 percent more accurate than typical content-based image-search methods, says Nuno Vasconcelos, a UCSD professor. **Kate Greene**

CATALYSTS

CO_2 to Fuel

Researchers at the University of California, San Diego, have shown that solar energy, with the help of catalysts, may be able to convert carbon dioxide into oxygen and carbon monoxide, which can then be used to make synthetic fuels.

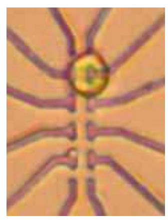
Here's how it would work: sunlight passes through carbon dioxide dissolved in a solution and is absorbed by a semiconductor photocathode, which converts the photons into electrons. The resulting current splits the carbon dioxide, much the way electricity can split water into hydrogen and oxygen. But in this case, the splitting is aided by two catalysts. One, at the cathode, helps produce carbon monoxide. The anode is made of platinum, which catalyzes the production of oxygen.

The prototype cathode, made from silicon, needed supplemental electricity to split the carbon dioxide. But the UCSD group is now experimenting with a gallium phosphide version *(left, with circular metal contacts)* that could run on sunlight alone. —*Kevin Bullis*

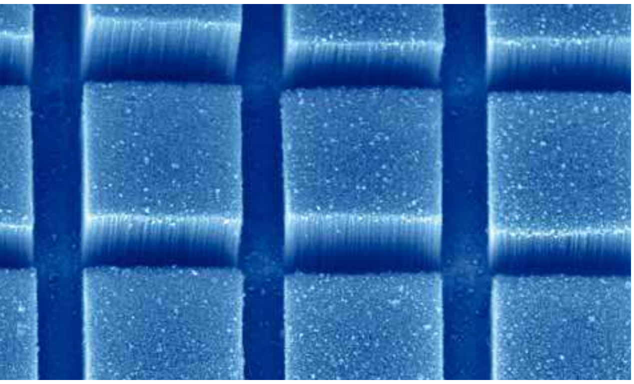
SENSING

Death of a Cell

Scientists at the University of Manchester have recorded a cell's final pulse of electrical activity. As part of an experiment to understand cellular signaling mechanisms, the researchers built an array of charge-sensitive semiconductor electrodes and placed a yeast cell on top of it *(right)*. The researchers detected variations between charge readings from the electrodes, measuring the flow of ions that cells need to stay alive. After dousing the cell with ethanol to make its electrical activity easier to detect, physicist Andre Geim measured ion flow to a resolution of about 10 ions. Sadly, the ethanol killed the cell. The last detectable ion reading "was probably the last gasp," Geim says. —*Duncan Graham-Rowe*



IRINA BARBOLINA, UNIVERSITY OF MANCHESTER (CELL); AARON SATHRUM, UCSD (CO2); COURTESY OF THE STATISTICAL VISUAL COMPUTING LABORATORY, UCSD (IMAGES)



ENERGY

All-Day Solar Cells

Solar cells crank out the most power at noon, when the sun is at its highest point. But researchers at the Georgia Tech Research Institute have come up with a prototype that works best in the morning and afternoon. Their solar cell, whose surface consists of hundreds of thousands of 100-micrometer-high block-like towers *(above)*, operates at high efficiencies through much of the day by catching light at many angles, with peak performance when the sun is at a 45° angle. "At an angle, the light has an opportunity to reflect off the sides of the towers," says Jud Ready, senior research engineer at the institute's Electro-Optical Systems Laboratory.

The solar cells are still not efficient enough for commercialization, but Ready is working on optimizing the size, spacing, and chemical composition of his towers. He sees the cells finding their first applications in spacecraft and satellites; cells that don't require mechanical means to stay sun-facing would be especially useful in space. —*David Talbot*

A sensor node sits on a rooftop at BBN Technologies; planned node sites are shown below.

WIRELESS

Sensor City

One hundred telephone poles in Cambridge, MA, will soon host wireless sensors that will allow researchers to track weather more precisely, discover when and where pollution peaks, and test new technologies that could lead to better Wi-Fi.

Anyone will be able to run experiments using the sensor network, says Matt Welsh, a professor of computer science at Harvard University, who is one of the project's lead investigators. So far, there are five nodes apiece on the campuses of Harvard and BBN Technologies, which is partnering with Harvard on the project.

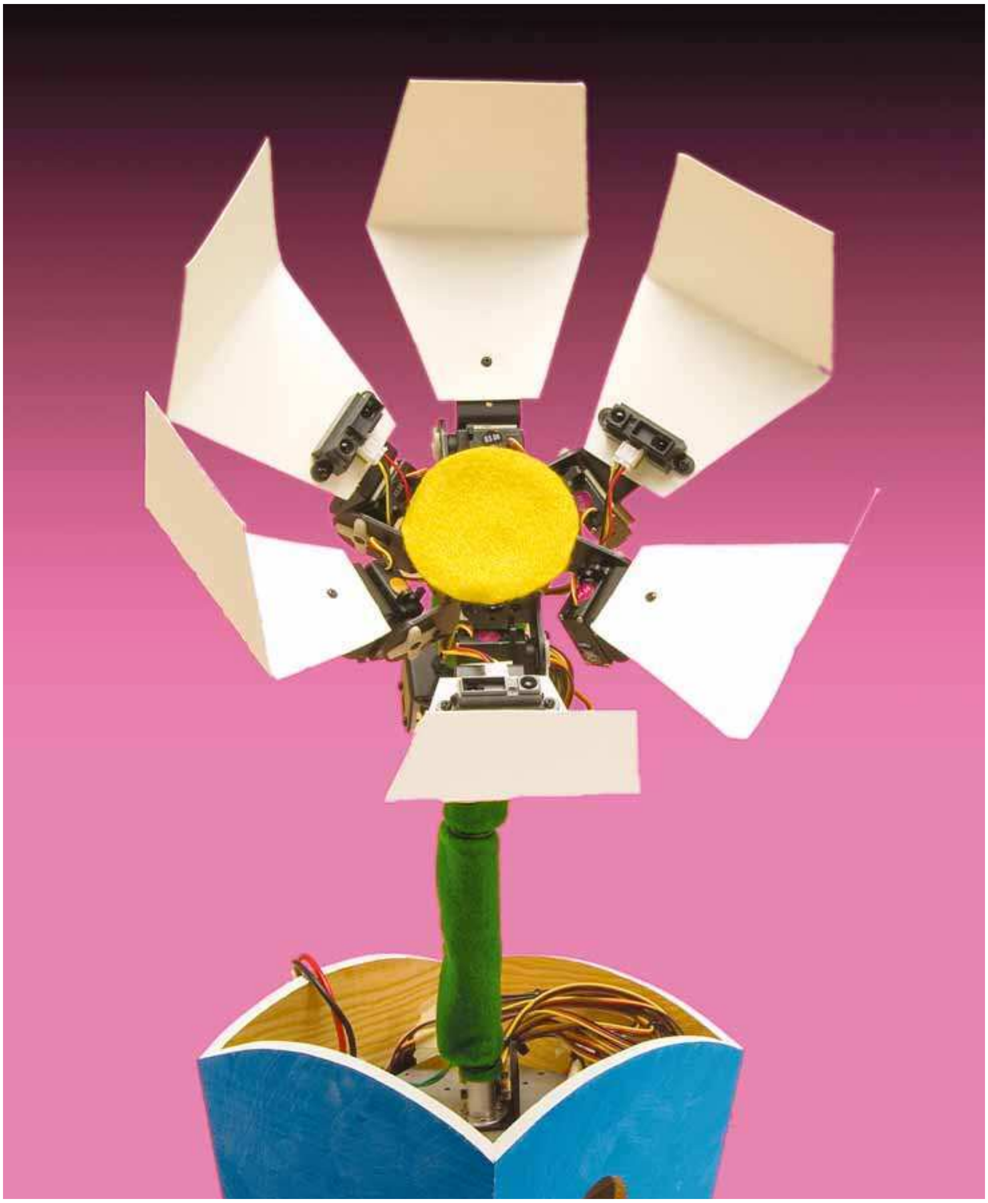
The first batch of weather and pollution sensors could help doctors advise asthma patients to stay away from certain areas at certain times. Eventually, motion sensors could measure traffic flow or even monitor parking spaces. The network could also be modified to monitor public transportation, helping people find out exactly when the next bus is coming. **Kate Greene**

SOCIAL NETWORKING

Dogs Tags for Virtual Sniffing

If you're in Boston this summer and see a funny device hanging off a pooch's collar, don't be surprised. A startup called Snif Labs, which grew out of MIT's Media Lab, is testing a technology designed to help dogs—and their owners—become better acquainted. When dogs wearing Snif's tags come within range of each other, the tags can swap ID codes. When the dogs' owners get home, they can use the company's social-networking service to trade information about their dogs and themselves. Your dogs have made a connection, the thinking goes; maybe you'd be willing to share advice, dinner, or more. Already, dog owners can meet online through canine-centric websites. "The Internet gives people the freedom to share information; the dog becomes a kind of online avatar," says Ted Rheingold, founder of Dogster, a social-networking site for people and their dogs. Snif's tags import the same idea into the real world. Snif—which stands for "social networking in fur"—also lets humans use the Internet to monitor the activities of pets left at home. —*Clark Boyd*

JOSH BERS, BBN TECHNOLOGIES/COURTESY OF MATT WELSH, HARVARD UNIVERSITY (SENSOR); COURTESY OF JUD READY (SOLAR); FRED RIX (DOGS)



ROBOTICS

Democratizing Robot Design

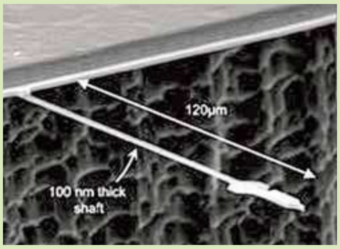
Beneath the white paperboard petals of this robotic flower—which can open and close in response to changes in light—lies a new robotics platform that Illah Nourbakhsh of Carnegie Mellon University hopes will launch an open-source robotics movement and "democratize robot design for people intimidated by current techniques and parts." Nourbakhsh and his colleagues at the CMU Robotics Institute say the platform, called Qwerk—it's inside the blue pot, above—is the first easy-to-use, low-cost robotics controller to house, in one place, power regulators, motor controllers, and hardware and software for an Internet connection and simple programming. By affixing off-the-shelf parts to Qwerk, people can create their own robots, such as wheeled remote-sensing devices, in just a few hours. The gadget is being commercialized by Charmed Labs of Austin, TX. **Michael Patrick Gibson**

JON LISBON (ROBOT); COURTESY OF IBM ALMADEN RESEARCH CENTER (MRI)

IMAGING

MRI at 90 Nanometers

To determine the function of a protein, you often have to determine its three-dimensional structure. That typically means crystallizing the protein and bombarding it with x-rays, but scientists would like to use magnetic resonance imaging (MRI) instead. Now, researchers at IBM's Almaden Research Center in San Jose, CA, have demonstrated a version of MRI that can image features as small as 90 nanometers. "For the first time, [we're] moving an MRI imaging technique into the nanoscale,"



says Dan Rugar, manager of nanoscale studies at the lab.

The IBM researchers built a 100-nanometer-thick silicon cantilever *(above)* that has a calcium fluoride test sample at the free end. They moved the cantilever slowly over a conical magnetic tip while manipulating the nuclei of the fluoride atoms in the sample with a high-frequency magnetic field. The cantilever's vibrations, driven by tiny magnetic forces, are measured by a laser and indicate the sample's size and shape. The system is too coarse to image proteins, which measure three to ten nanometers across. But the IBM team hopes to sharpen its resolution to less than a nanometer so that atoms can be pinpointed within a protein, allowing scientists to reconstruct its structure. *—Prachi Patel-Predd*

STARTUP

Better Biofuels

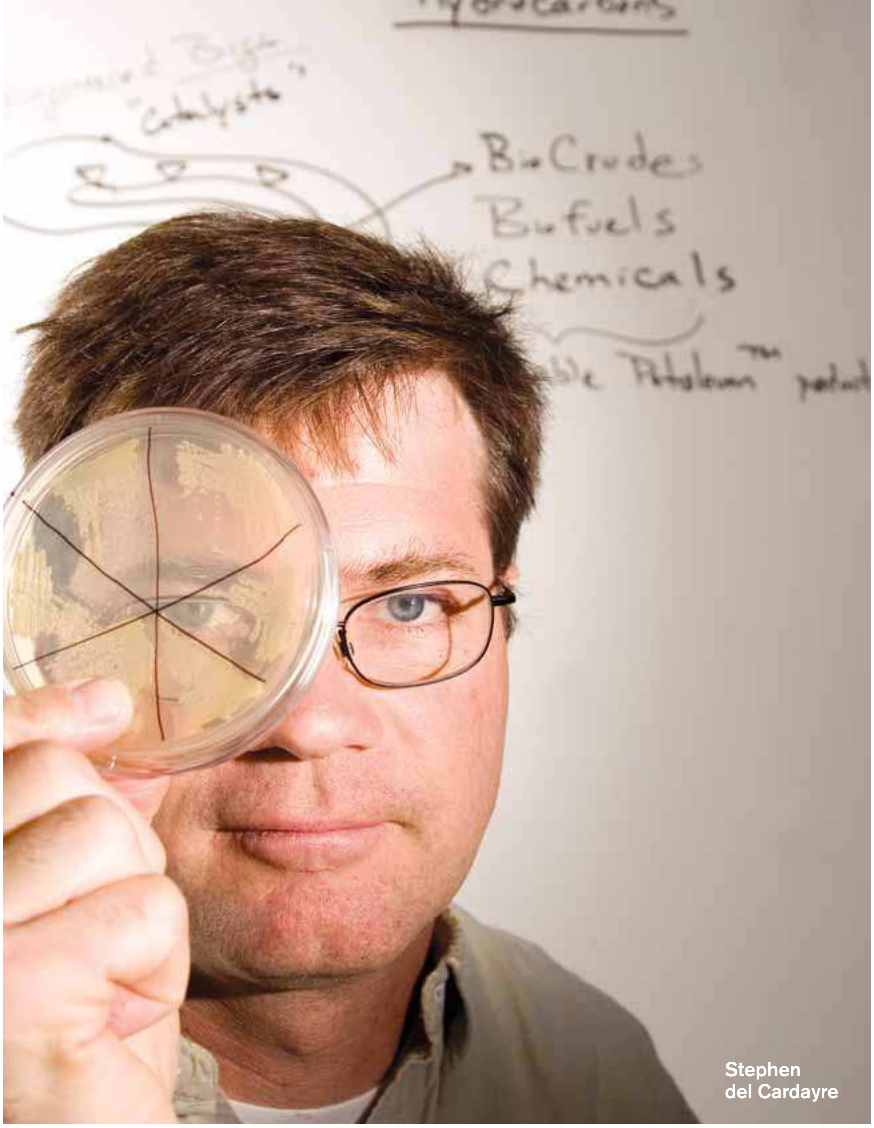
Using synthetic biology, LS9 custom-makes hydrocarbons

The U.S. Department of Energy has set a goal of replacing 30 percent of gasoline used in the United States with fuels from renewable biological sources by 2030. So it is hardly surprising that some biotech startup companies are positioning themselves to take advantage of an anticipated booming biofuels market.

While much of the focus is on ethanol, LS9 of San Carlos, CA, is using relatively new "synthetic biology" techniques to engineer bacteria that can make hydrocarbons for gasoline, diesel, and jet fuel. Hydrocarbon fuels are better suited than ethanol to existing infrastructure, and their manufacture would require less energy.

LS9 is at a very early stage, but it has brought together leaders in synthetic biology and industrial biotechnology. The company is equipping microbes with gene pathways that play a role in energy storage in other microbes, plants, and even animals. Other startups, such as Amyris of Emeryville, CA, and SunEthanol of Amherst, MA, are also trying to use synthetic biology to develop biofuel-producing microörganisms. LS9's microbes produce and excrete hydrocarbons that are useful as fuels, says Stephen del Cardayre, vice president for research and development. Now the company is working to customize the microbes' products and boost outputs. "We certainly have gone beyond what we think anybody else was even thinking of doing" in terms of producing hydrocarbons, says George Church, a geneticist at Harvard Medical School and an LS9 cofounder.

Noubar Afeyan, CEO of Flagship Ventures, an LS9 funder, cautions that no one can tell the extent to which any biofuel will displace fossil fuels. But, he adds, "the opportunity is so large that I don't have to believe in much more than a few percentage points of market penetration for it to be worth our investment." The company is looking for areas where synthetic biology's potential to produce specific types of molecules will pay off. This could mean making high-performance jet fuel, Afeyan says, or creating gasoline that has no pollution-causing sulfur content. LS9 also foresees licensing its technology to ethanol producers. Del Cardayre notes that ethanol contains 30 percent less energy than gasoline, can't be delivered through existing pipelines, and must be mixed with gasoline before being burned in conventional engines. LS9's fuels would have none of those disadvantages. What's more, the fuels could be produced more efficiently. For example, at the end of ethanol fermentation, the mixture has to be distilled to separate ethanol from water; LS9's products would just float and be skimmed off. Overall, LS9 says, its process would consume 65 percent less energy than ethanol production. The company hopes to bring hydrocarbon biofuels to market in four or five years. **Neil Savage**



Stephen del Cardayre

SAUL BROMBERGER AND SANDRA HOOVER

Company: LS9, San Carlos, CA
Funding: $5 million
Technology: Synthetic biology to produce microbes that excrete hydrocarbons
Investors: Khosla Ventures, Menlo Park, CA; Flagship Ventures, Cambridge, MA
Founders: George Church, geneticist, Harvard Medical School; Chris Somerville, plant biologist, Stanford University
Acting CEO: Douglas Cameron, former director of biotechnology research at Cargill, chief scientific officer at Khosla Ventures

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THURSDAY, SEPTEMBER 27

Opening Keynote

Sky Dayton, CEO, Helio
Dayton, an Internet revolutionary since the age of 23, now heads Helio, a dynamic mobile company that focuses on personal connectivity with a creative flair unmatched in today's ever-changing mobile market. Find out how his vision for the future of the mobile world will affect multiple industries.

Keynote Panel: Creating Media

Guillaume Cohen, CEO, Veodia; **Di-Ann Eisnor**, CEO, Platial; **Carlos Garcia**, CEO, Scrapblog; **Dan Gillmor**, Founder, Center for Citizen Media
From personal Web pages and blogs to podcasts and video sharing, what's next in personal publishing? Leaders from the top content-creation companies discuss their technologies, with live demonstrations.

Fireside Chat

Ann Winblad, Partner, Hummer Winblad Venture Partners
Learn how Winblad's 25+ years of expertise can help you grow your business. This author, advisor, and cofounder of Hummer Winblad Venture Partners has been a key player in launching some of the most successful software companies.

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The Nintendo Wii

Though it can't boast the cinema-quality graphics of its competitors, the Wii game console distinguishes itself with its controller scheme. By Daniel Turner

Initially discounted by game-industry watchers as graphically underpowered compared with the Sony PlayStation 3 and Microsoft Xbox 360, the Nintendo Wii has wiped the sales floor with its competitors. In February 2007, 335,000 Wiis were sold in the U.S., versus 228,000 Xbox 360s and 127,000 PS3s. Behind the Wii's success is its unique controller: simple and wireless, it responds to your movements in a natural manner, turning into a baseball bat, a sword, or a hand, as necessary. It is, in a word, fun.

A MEMS Sensor 1 (Wii Remote)

The key to the Wii's main controller is its three-axis microelectromechanical-system (MEMS) accelerometers, which measure movement in three dimensions. Two-dimensional MEMS sensors have been around for a while, but adding the third axis presented challenges. "You have moving parts that you have to protect from the environment," says Christophe Lemaire, a marketing manager at Analog Devices, which makes the sensor used in the Wii Remote. Most MEMS sensors come in hermetic packages made from ceramics or metals. But this increases the devices' size and cost—a problem that the additional sensory dimension was only going to aggravate. "What we do," says Lemaire, "is put a cap over the sensor elements at the wafer level." That creates a hermetic cavity and enables the use of a cheap, small, lightweight case.

B Bluetooth

The Wii Remote uses a Broadcom Bluetooth chip to wirelessly send a constant stream of position, acceleration, and button-state data to the Wii console. The chip also contains a microprocessor and RAM/ROM memory for managing the Bluetooth interface and converting voltage data from the accelerometers into digitized data.

CHRISTOPHER HARTING

D Infrared Sensor Bar

The accelerometers in the controls gauge movement but not position relative to the TV screen. So the Wii comes with a “sensor bar,” to be placed at the top or bottom of the screen. The bar sends out an infrared signal, which is picked up by detectors at the front of the Wii Remote. The Remote uses distance and angle information to triangulate its location, which it sends, along with acceleration data, to the console.

C MEMS Sensor 2 (Nunchuk)

Many games on the Wii take advantage of a second controller, called the Nunchuk, which plugs into the Wii Remote. It features an analog joystick and two buttons, but it also has its own MEMS accelerometer, this one provided by STMicroelectronics. Benedetto Vigna, an STMicroelectronics physicist, says that the company’s three-dimensional accelerometer had a “really quick” development time; the company first met with Nintendo about the Wii in March 2005, only nine months before the product shipped. Vigna notes that there are two chips inside the 5-millimeter-by-5-millimeter-by-1.5-millimeter plastic package—the accelerometer and another chip that translates the tiny wiggles of the sensor into voltage. As in the Wii Remote, the voltage readings are then translated into motion data by a microprocessor, and the data are transmitted wirelessly from the Wii Remote via Bluetooth to the Wii console.

Wi-Fi

Nintendo saw the value of adding Wi-Fi wireless connectivity to its popular DS handheld gaming device, which allowed users to play against others wirelessly, so it did the same with the Wii. If you have an Internet connection, you can use the Wii to surf the Web or access information hosted on Nintendo’s servers, such as weather and news. Developers have said there will be Wii games that offer online play, though as of this writing only one—a Pokémon title—has been released.

Find out more about how the Wii works and play a bowling game at **technologyreview.com/wii.**

George Whitesides

The chemistry of energy

George Whitesides is a chemist with a knack for translating lab discoveries into things the world finds useful. He has cofounded numerous companies, including the biotech giant Genzyme. In the late 1980s and 1990s, Whitesides, a professor of chemistry at Harvard University, helped make possible today's nanotechnology boom by demonstrating the possibility of engineering molecules that self-assemble into ordered materials. Now he is turning his attention to finding solutions to today's energy crisis. Gleaning new insights from fundamental chemistry, he says, will be crucial to meeting energy needs and cutting increases in greenhouse-gas emissions. *TR*'s nanotechnology and materials science editor, Kevin Bullis, visited Whitesides in his Harvard office to ask how chemistry can help.

***TR:* Why is chemistry central to energy?**

Whitesides: Wind power is just wind powering a turbine. With nuclear, the actual power generation of course comes from the disintegration of the nucleus, which is a physics event instead of a chemistry event. But essentially, everything else is chemistry. You take fuel and you burn it, and that's chemistry. When you run a battery, various elements change their oxidation state, and that's chemistry. Even in the process of making a solar cell, the crucial steps are largely chemistry. From a flame to a battery to a solar cell, the crucial elements are chemical.

What are our options for cutting down on carbon emissions while meeting our vast energy needs?

If the only issue were supply, we could burn a lot of coal and build lots of nuclear plants, and at least in the United States, for the foreseeable future we could have a fair amount of [energy] supply. Because of climate changes, it's not just a question of producing energy. It's a question of producing energy in a way that we can live with in the long term.

If you look at the available pieces, from conservation to nuclear, solar, whatever, and you put them all together, we can't do it. We have to do something differently, and we have to come up with new ideas. This is not just an engineering problem of taking things that we know and applying them better.

How can basic chemistry research help?

There's a lot of enthusiasm right now for photosynthesis as a method of both fixing carbon and harvesting sunlight in the form of plant matter, whether it's plant oils that can be converted into biodiesel or biomass that's somehow converted into butanol or ethanol. Those processes are a long way from being as efficient as they might be. If we could find a way to dramatically improve the efficiency of photosynthesis, that could be interesting. Can we look at the enzymes that are involved—the catalysts—and tinker with them, readjust them so that they become more efficient?

We understand many of the pieces of the overall process of going from sunlight and carbon dioxide and water to carbohydrates, but there's a lot that we don't understand. To reëngineer photosynthesis, we first have to understand it.

But relying heavily on biofuels could have unintended effects, such as raising food prices. Unless we understand the overall system, the things we try to do to make things better …

… can make things worse.

Cellulosic ethanol has some good features. But it has all sorts of problems. We don't know what the energy costs are of doing this. You need some energy to collect the stuff, and to do the processing and to distill the fluids. There's the question of whether we really can make large quantities of it. It's seasonal. You can only do it in parts of the country. You have to then think about taking this relatively low-energy thing, biomass, and collecting it to a central processing station. You can't afford to ship this stuff over large distances, which means the processing plants are small and intrinsically inefficient for large-scale production. And should we think of topsoil in Iowa as a renewable or a nonrenewable resource? We think about the problem of depleting petroleum reservoirs, but what about the problem of depleting Iowa topsoil? We don't know how this set of energy technologies all fits together. How do we do agricultural energy production, and how do we think about agricultural land overall—for example, the competition of energy with food production, and just the mere fact that the soil can wear out if it's not managed correctly?

So what is the solution?

We need long-term investment. We need new ideas. We need a cadre of young people to work on it. This is not a Manhattan Project. It's not something in which we have a single engineering objective and if we can solve that, the mission is accomplished. It's going to have a large number of components: Understanding photosynthesis. Understanding how to most efficiently make solar cells. Making hydrocarbon-fuel combustion more efficient. Making energy transmission more efficient. Understanding how the pieces work together so that if we do this, we know we're not actually going to make the situation worse. TR

ASIA KEPKA

THE INTERNET

Building an Immersive Web

Tomorrow's virtual worlds depend on real collaboration today, argues **Colin J. Parris**.

Early virtual worlds such as Second Life demonstrate that highly visual, 3-D online environments hold the potential to transform the way humans interact not only with computers but with each other *(see "Second Earth," p. 38)*. Hyped as they are, these immersive environments address two fundamental aspects of being human: our visual and social natures.

To make these platforms viable for business and consumer uses other than Second Life, the technology and business communities must begin collaborating now, because significant challenges lie ahead.

First, we need to develop and implement open standards that can connect virtual worlds and enable users to pass from one to the next, just as we can easily go from one Web page to another. The idea of jumping from, say, Second Life to the immersive game World of Warcraft might seem far-fetched today, but I remember how far off today's easy Internet surfing seemed back in the early 1990s.

Since then, Web languages like HTTP and HTML have helped ignite an explosion of online content and creativity. Likewise, removing barriers between different environments will let innovations that might otherwise be limited to one world affect a much broader audience.

Second, we need to develop reliable methods of managing trust and identity in order to head off the privacy and security violations that we are likely to face in virtual worlds. Constantly evolving security threats plague the Web today and, perhaps more than any other single factor, pose barriers to e-business.

Today's typical security infrastructure is a patchwork of disparate mechanisms and tools spanning the network, operating-system, and application levels. However well these mechanisms work individually, their failure to consistently work well together creates security vulnerabilities. With virtual worlds, we have a chance to build security capabilities from the ground up and address interoperability problems before they become major weaknesses. Of course, new technologies will inevitably raise new security questions, but it will be useful for companies building virtual worlds to consider security lessons learned from the Web.

Finally, for virtual worlds to have any meaningful impact on business and government, we must leverage current business applications and data repositories—whether they are Web-built, Web-enabled, or legacy systems—by integrating them into virtual worlds. This is an absolute must for the rapid dissemination and widespread adoption of virtual-world business technologies. The integration of existing applications and recently developed ones will, again, require coöperation around open standards.

As different virtual worlds and applications become more fully integrated with the current Web, we will see amazing transformations, both in the way consumers interact with companies and in the way employees inside businesses interact with each other and with outside communities.

Some of us are eager to push the boundaries of what might be possible in virtual worlds and the 3-D Internet. But before we can do so, we must partner with other businesses and societal leaders. When that happens, pervasive virtual worlds will no longer seem a distant reality. TR

Colin J. Parris is vice president of digital convergence in the IBM Research Group.

BIOTECHNOLOGY

Metagenomics Defined

Genomics will help explain the microbial world, says **Ed DeLong**.

This spring, the National Research Council released a report titled "The New Science of Metagenomics: Revealing the Secrets of Our Microbial Planet." To many, the term "metagenomics" might seem abstract—after all, it does sound like "metaphysics." So what is microbial metagenomics, and what is its relevance to the future of biology, biological engineering, and biotechnology?

Conventional genomic research on microörganisms determines the DNA sequences of individual microbes by examining cultivated strains. In metagenomics, DNA sequence information is extracted from entire microbial communities in situ. Metagenomic approaches use this bulk data to infer underlying properties of both individual microbes and microbial communities as a whole.

Metagenomics advances the understanding of complex microbial systems in several ways. Microbe cultivation efforts have failed to recover many of the microörganisms that predominate in a variety of natural and man-made settings. The majority of extant microbial species and their behaviors therefore represent a vast biological terra incognita. Metagenomic approaches, which side-

ILLUSTRATIONS BY JOHN HERSEY

step the need to purify and cultivate individual microbial strains, make it easier to retrieve genome sequence information from elusive microbial species. A second, and perhaps more important, point is that microbial species do not generally occur as single strains or pure cultures. Rather, any given microbial assemblage can consist of hundreds of different species, each one displaying significant genetic variability. The biological meaning and functional consequences of this tremendous within- and between-species biodiversity remain obscure. Metagenomic approaches enable direct assessment of community diversity and provide data sets relevant to both measuring and modeling biological processes.

Microbial communities in humans will no doubt be intensively studied using metagenomic approaches. Already, the complex interplay between human genotype and phenotype, and the associated microbiome composition and response, is becoming clearer *(see "Our Microbial Menagerie," p. 58)*. But other uses of metagenomics will also be important. Energy applications, including microbially produced biofuels and new processes for biomass conversion, are a good example. The study of anthropogenic effects on microbial processes that regulate the mass balance of planetary carbon and nitrogen cycles will also benefit from metagenomics.

Like the human genome sequence, the results of metagenomic analysis represent a type of "parts list" that does not fully capture the functional properties, interrelationships, and dynamics of living microbial communities. They do, however, begin to extend our analytical reach beyond the single organism. Population genomics, "community metabolism," and genomic comparisons of different microbial communities are all now possible. We are not so far away from a systems biology that will provide a more holistic and accurate picture of the whole hierarchy of biological systems—from molecular, subcellular, and intercellular interactions to populations, communities, and ecosystems. TR

Ed DeLong is a professor in the Biological Engineering Division and the Department of Civil and Environmental Engineering at MIT.

MATERIALS

Green Concrete

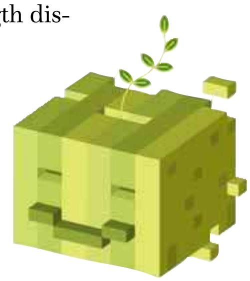
Nanoengineered materials, says **Franz-Josef Ulm**, could reduce greenhouse-gas emissions.

Protecting the built environment from the forces of the natural world with dams and seawalls is important work *(see "Saving Holland," p. 50)*, as is protecting the natural environment from the engineered world. But the 21st-century engineer should also look to the natural world as a powerful design partner and a source of sustainable solutions. A good place to begin is by studying the way natural materials are constructed at the nanoscale and drawing inspiration from them as we engineer our own materials. Take, for example, the civil engineer's construction material of choice: concrete, the oldest engineered building material and one of the most widely consumed materials on earth, second only to water.

Each year, 1.89 billion tons of cement—the primary component of concrete—are manufactured, enough to produce one cubic meter of concrete for every person alive. Unfortunately, cement is a major source of atmospheric carbon dioxide—largely because it's made by burning fossil fuel to heat a limestone and clay powder to 1,500 °C, which changes its molecular structure. When the cement powder is later mixed with water and gravel, the invested energy is released into chemical bonds that form calcium silicate hydrates—the glue that binds the gravel to make concrete. The production of cement accounts for an estimated 7 to 8 percent of all human-generated carbon dioxide emissions.

If we can engineer a novel cement whose manufacture produces only half as much carbon dioxide, we will achieve a significant reduction in total carbon dioxide emissions. And human bone could show us how to do it.

Cement's strength comes largely from the way the calcium silicate hydrates self-assemble into particles that pack together with the highest density possible for spherical objects. Human bone—or, more precisely, the apatite minerals in bone—achieves a very similar packing density at the nanoscale, yet it is "manufactured" at body temperature with no appreciable release of carbon dioxide. At the nanoscale, bone has much in common with concrete: it consists largely of calcium; its strength displays a significant frictional component; and collagen proteins help reinforce it, much as steel bars reinforce concrete.



Of course, with bone, the hydration and hardening of the apatite minerals takes a month or so, more time than we can afford on construction sites. But if we can find a way to mimic the process and speed it up, we could replicate it to fashion a new building material.

This is but one example of research drawing on the limitless designs offered by the natural world—and extracting fundamental engineering principles from them. TR

Franz-Josef Ulm, an expert on materials, is a professor in MIT's Department of Civil and Environmental Engineering.

Careers in Motion

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Career Growth Profile

Marco Murgia might have launched his career working for computer giant Hewlett-Packard, but he realized his true passion when he entered the entrepreneurial arena of high-tech startups. Since 2002, he has worked with Caymas Systems of San Jose, CA, which designs identity-based technology that provides a single platform for granting secure remote access and network access to company information and applications.

As Caymas Systems' chief technology officer and chief architect, Murgia is charged with ensuring that the company's products meet both technical and business requirements. He also represents the company's technology to large customers and partners. His ability to analyze Caymas's products from the viewpoints of both an architect and a businessman is something Murgia credits largely to his master's degree in engineering management.

"My degree has given me a different perspective on business and the tools by which to participate more directly in the running of a company," says Murgia, who earned his master's from Stanford University in 1995 while working for HP in Cupertino, CA.

With a bachelor's degree in electrical engineering from MIT already under his belt, Murgia decided to pursue a master's degree after watching several of his peers at HP go through Stanford's engineering management program and return to take on bigger leadership roles within HP.

MARCO MURGIA

Age: 42

Job Title: CTO and chief architect

Employer: Caymas Systems

Program: MS, Engineering Management, Stanford University

"I was getting restless working at a big company and feeling like a bit of a cog in a larger machine," he admits. "I wanted to be more influential. I felt that I was very technical but didn't have the business background to be as effective as I could be."

Fortunately, HP made it quite easy for Murgia to pursue a graduate degree. The company participates in the Stanford Instructional Television Network (SITN), an interactive distance-learning program that allows executives to "attend class" while on site at their workplaces. Through the SITN program, Murgia took one class per quarter, which "met" for an hour two to three times per week.

"HP allowed me flex-time options so I could attend class during the workday and then work later to make it up," he says. "Homework was done in the evenings. One class at a time was manageable while working full time."

However, Murgia soon expedited his academic pur-

suits when he qualified for and was granted an educational fellowship through HP. The company-sponsored program allowed him to take up to 12 months off work to go back to school full time. The fellowship paid 100 percent of his tuition and 75 percent of his salary to cover living expenses.

"The fellowship allowed me to focus on school," he says. "Going to school part time while holding a job is a series of trade-offs. Sometimes one or the other can suffer due to split priorities. While it's not financially feasible for some, if at all possible, try to do some of your schooling full time. The focus will increase what you get out of it."

Murgia says his graduate-school experience gave him insight into the world of entrepreneurship, which eventually led him to leave HP and venture into startups.

"Going back to school gave me the beginnings of a network outside of HP," he says. "The contacts you make at school can have a big impact on your career further down the road." To learn more about the benefits Murgia experienced after finishing his master's degree, visit www.technologyreview.com/resources/career/

Do you have a career success story? Send a synopsis to career@technologyreview.com.

Ask the Expert

Roberta Chinsky Matuson, principal at Human Resource Solutions, has over 27 years of experience in human resources.

From online degrees to weekend classes, universities are making it easier for executives to keep their day job and earn a graduate-level degree simultaneously. Taking the time to analyze your career goals, educational objectives, and personal commitments will help you choose a program that is tailored to your needs. Roberta Chinsky Matuson, a former human-resources careers expert for Monster.com and a principal at Human Resource Solutions, suggests asking yourself five questions to determine which academic avenue is right for you. www.technologyreview.com/resources/career/

Do you have a question for our experts? E-mail us at career@technologyreview.com.

Program Directory

JASON MADARA

Photo Essay

NASA's Next Telescope

The James Webb Space Telescope is scheduled to be deployed in 2013, giving scientists a deeper look into space than the existing Hubble Space Telescope. Its task will be to gather infrared light from objects more than 13 billion years old, using technologies that until recently did not exist. **By Brittany Sauser**

The new telescope's primary mirror (opposite page) is more than six meters in diameter, with a surface area seven times that of Hubble's. The mirror's size will allow the telescope to collect more light more quickly than previous telescopes and achieve better resolution. "It is extremely lightweight, with very precise optical surfaces," says John Decker, the deputy associate director of the project at NASA.

To manage such an enormous mirror, engineers have divided it into 18 pieces that will be folded together; they'll be unfolded while the telescope is traveling to its final destination. Each segment is ground and polished to precise optical specifications (this page). Engineers are taking extra precautions to avoid a repeat of the Hubble mishap, in which the mirror was incorrectly ground and polished, causing the telescope to produce blurry images until a service mission adjusted it.

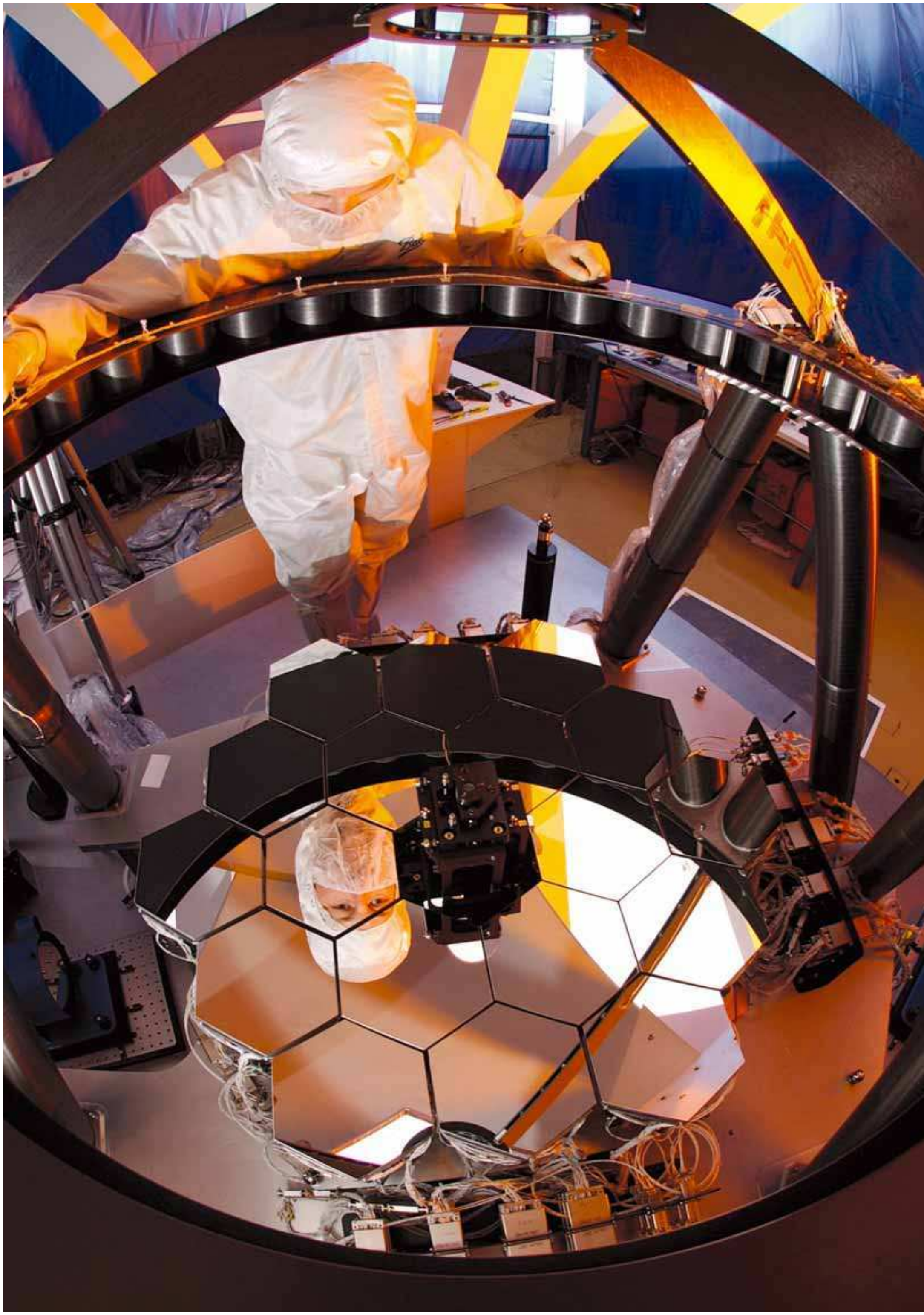
JASON MADARA

The telescope's mirror is made out of beryllium, one of the lightest metals known. A close-up view of the material is shown on the opposite page. Beryllium has exceptional thermal properties that give it stable optical performance at a wide range of temperatures. It is also thermally conductive, which helps keep the mirror's temperature constant.

The mirror segments will be held in place and supported by a backplane (above) built by Alliant Techsystems. This structure is crucial in that it keeps the mirror steady; any unwanted movement could distort images.

The mirror segments will have seven degrees of freedom: scientists will be able to tip, tilt, and focus them separately without compromising their ability to act as a single optical device. The software that controls the segments was developed by NASA and Ball Aerospace. To validate its performance, Ball engineers have built a one-sixth-scale optical test bed (right). The mirrors in the test bed are a small-scale version of the real thing.

COURTESY OF NASA MARSHALL SPACE FLIGHT CENTER; COURTESY OF BALL AEROSPACE



MARK ALLEN JOHNSON / WPN

A full-scale model of the telescope (right) was on display in Seattle in January. It is more than 24 meters long and weighs 12,000 pounds.

To help it record faint signals from faraway objects, engineers at Raytheon Vision Systems and Teledyne Technologies have built two sensitive infrared detectors that register mid- and near-infrared wavelengths. The detectors are responsible for turning collected photons into electrons, much as a digital camera does, so that images of stars and galaxies can be recorded electronically. At left, the mid-infrared detector is exhibited by a project scientist at NASA's Jet Propulsion Laboratory, where it is being tested.

Further enhancing the telescope's ability to detect faint light is a microshutter built by engineers at NASA's Goddard Space Flight Center. It serves as a light filter, allowing scientists to select the object they wish to study and block nearer, brighter light sources. With the help of this device, the telescope can efficiently observe more than 100 distant galaxies simultaneously.

Since the telescope will be operating at extremely cold temperatures (30 to 55 K), it must not generate heat that could drown out the radiation scientists are trying to detect. Engineers at Northrop Grumman have designed a large sun shield (below) to block the heat of the Sun and Earth. It consists of five layers of silicon-coated Kapton to reflect the Sun's heat back into space.

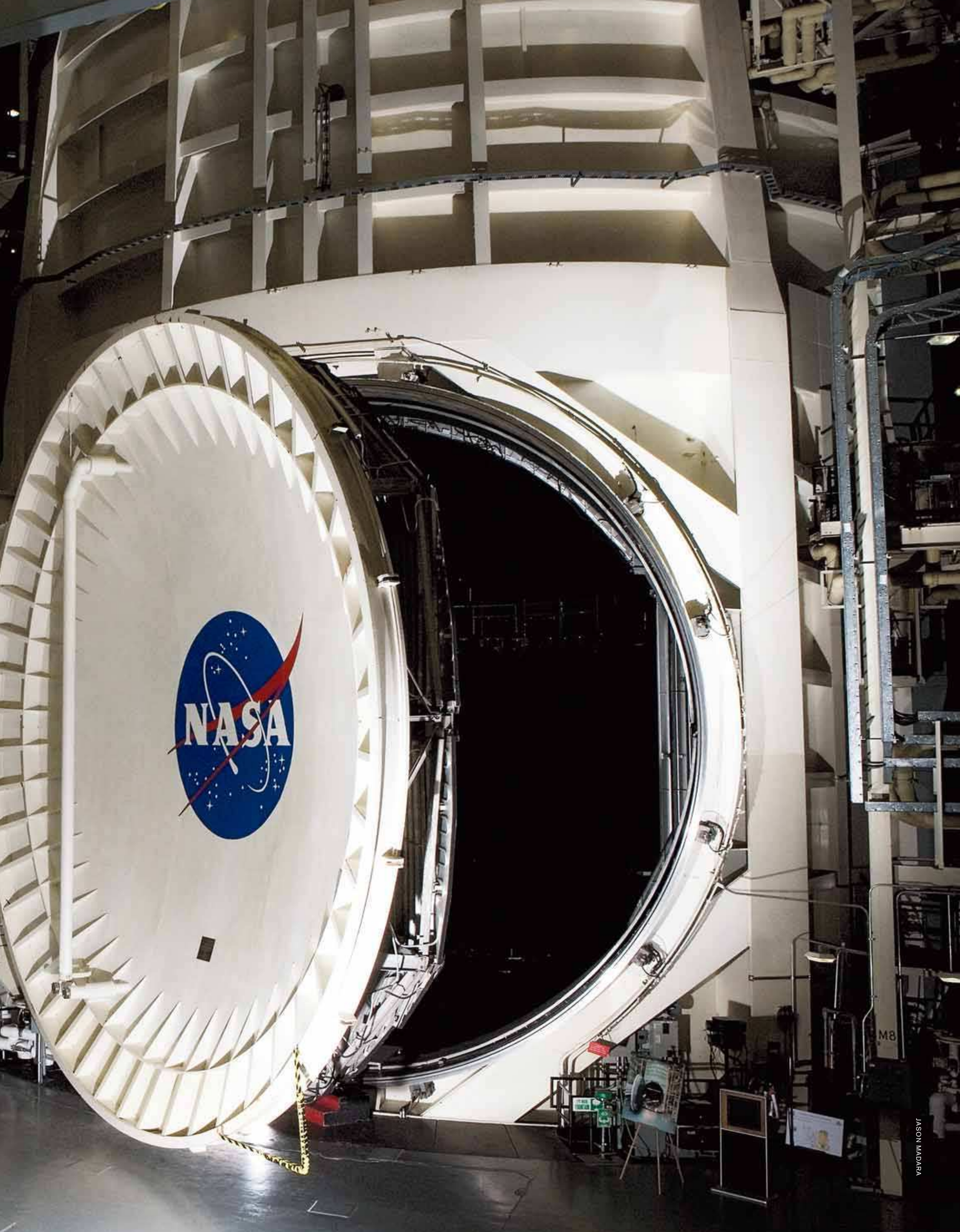
COURTESY OF NORTHROP GRUMMAN

Before the completed telescope is sent into space, a million miles from Earth, it will be tested in a thermal-vacuum chamber (opposite page) at NASA's Johnson Space Center in Houston. The chamber is 19.8 meters in diameter and 36.6 meters high. Its door alone weighs 40 tons.

Thus far, the chamber has been used mostly to test objects destined for low Earth orbit, so it will need to go through a series of modifications before it can simulate the cold temperatures the James Webb telescope will experience. New helium-cooled panels will be added to existing panels cooled by liquid nitrogen, allowing the chamber to reach a temperature of 30 to 35 K. The helium will also carry heat away from the panels.

The telescope will be put into the chamber by means of a mobile crane. Bringing the chamber and telescope to the desired temperature will take 30 to 40 days.

NASA engineers plan to start testing the telescope in 2010.



JASON MADARA

YOU ARE HERE? **In this imaginary composite, the virtual world of Second Life—as embodied in the author's avatar—meets the real world of Google Earth.**

The World Wide Web will soon be absorbed into the World Wide Sim: an immersive, 3-D visual environment that combines elements of social virtual worlds such as Second Life and mapping applications such as Google Earth. So why not call it

Second Earth

By Wade Roush

A thunderhead towers at knee level, throwing tiny lightning bolts at my shoes. I'm standing–rather, my avatar is standing–astride a giant map of the continental United States, and southern Illinois, at my feet, is evidently getting a good April shower.

The weather is nicer on the East Coast: I can see pillowy cumulus clouds floating over Boston and New York, a few virtual meters away. I turn around and look west toward Nevada. There isn't a raindrop in sight, of course; the region's eight-year drought is expected to go on indefinitely, thanks to global warming. But I notice something odd, and I walk over to investigate.

The red polka dots over Phoenix and Los Angeles indicate a hot day, as I would expect. But the dot over the North Las Vegas airport is deep-freeze blue. That can't be right. My house is only 30 kilometers from the airport, and I've had the air conditioner running all day.

"Any clue why this dot is blue?" I ask the avatar operating the weather map's controls. The character's name, inside the virtual world called Second Life, is Zazen Manbi; he has a pleasant face and well-kept chestnut hair, and the oval spectacles perched on his nose give him a look that's half academic, half John Lennon. The man controlling Manbi is Jeffrey Corbin, a research assistant in the Department of Physics and Astronomy at the University of Denver.

"Let me check something," Manbi/Corbin responds. "I can reset the map–sometimes it gets stuck." He presses a button, and fresh data rushes in from the National Oceanic and Atmospheric Administration's network of airport weather stations. The clouds over the East shift slightly. Los Angeles goes orange, meaning it's cooled off a bit. But there's still a spot of indigo over Vegas.

"I guess it's feeling blue," he jokes.

The map I am standing on belongs to NOAA, and it covers a 12-by-20-meter square of lawn on a large virtual island sustained entirely by servers and software at San Francisco–based Linden Lab, which launched Second Life in 2003. (On the map's scale, my avatar is about 500 kilometers tall, which makes Illinois about three paces across.) Corbin, who's on a personal mission to incorporate 3-D tools like this one into the science curriculum at Denver, paid Linden Lab for the island so that he could assemble exhibits demonstrating to the faculty how such tools might be used pedagogically. "Every student at DU is required to have a laptop," he says. "But how many of them are just messaging one another in class?" A few more science students might learn something if they could *walk inside* a weather map, he reasons.

Corbin's got plenty to show off: just west of the map is a virtual planetarium, a giant glass box housing a giant white sphere that in turn houses a giant orrery illustrating the geometry of solar eclipses. And he's not the only one to offer such attractions. Just to the south, on an adjoining island, is the International Spaceflight Museum, where visitors can fly alongside life-size rockets, from the huge Apollo-era *Saturn V* to a prototype of the *Ares V*, one of the launch vehicles NASA hopes to use to send Americans back to the moon.

Second Life, which started out four years ago as a 1-square-kilometer patch with 500 residents, has grown into almost 600 square kilometers of territory spread over three minicontinents, with 6.9 million registered users and 30,000 to 40,000 residents online at any moment. It's a world with birdsong, rippling water, shopping malls, property taxes, and realistic physics. And life inside is almost as varied as it is outside. "I help out new citizens, I rent some houses on some spare land I have, I socialize," says a long-time Second Lifer whose avatar goes by the name Alan Cyr.

"I dance *far* better than I do in real life. I watch sunsets and sunrises, go swimming, exploring, riding my Second Life Segway. I do a lot of random stuff."

But aside from such diversions, the navigation tools provided by Second Life—users can fly and hover like Superman and zoom between micro and macro views of any object—make it an excellent place to investigate phenomena that would otherwise be difficult to visualize or understand. In that sense, this hideaway from the reality outside is beginning to function as an alternative lens on it. Ever wondered when the International Space Station might pass overhead? At the spaceflight museum, your avatar can fly alongside models of the station, the Hubble Space Telescope, and many other satellites as they orbit a 10-meter-diameter globe in sync with real-world data from the Air Force Space Command. Or perhaps you suspect a bad call by the line judges at Wimbledon. If so, just stroll a virtual tennis court inside Second Life and examine the paths of every serve and volley of a match in progress, reproduced by IBM in close to real time.

Of course, from within a virtual world like Second Life, the real world can be glimpsed only through the imperfect filters of today's software and hardware. Barring a startling increase in the Internet bandwidth available to the average PC user or a plunge in the cost of stereoscopic virtual-reality goggles, we will continue to experience virtual worlds as mere representations of 3-D environments on our flat old computer screens. And your avatar obviously isn't really you; it's a cartoonish marionette awkwardly controlled by your mouse movements and keyboard commands. Moreover, at the moment, every conversation inside a virtual world must be laboriously typed out (although Linden Lab will soon add an optional voice-chat function to Second Life).

So while virtual worlds are good for basic instruction and data representation, professionals aren't yet rushing to use them to analyze large amounts of spatial information. For that, they stick to specialized design, animation, modeling, and mapping software from companies like Autodesk and ESRI. But there's another new genre of 3-D visualization tools that are accessible to both professionals and average Internet users: "virtual globe" programs such as Google Earth, Microsoft's Virtual Earth, and NASA's open-source World Wind. Virtual globes let you plot your city's sewer system, monitor a network of environmental

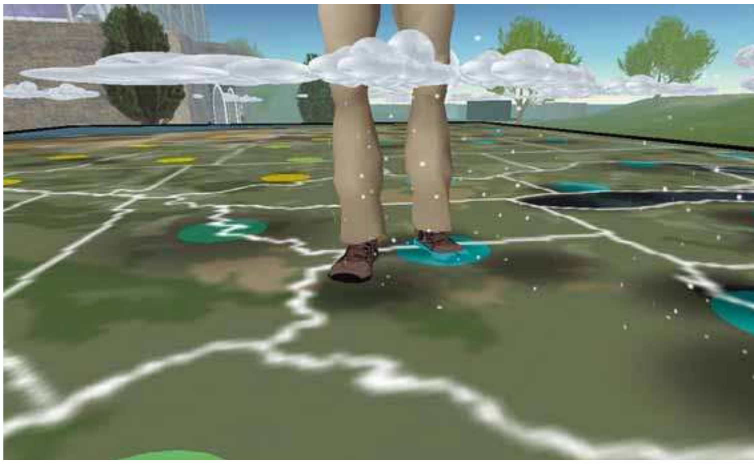
sensors, count up the frequent-flyer miles between New York and New Delhi, or just soar through a photorealistic 3-D model of the Grand Canyon.

Even as social virtual worlds incorporate a growing amount of real-world data, virtual globes and their 2-D counterparts, Web maps, are getting more personal and immersive. Digital maps are becoming a substrate for what Di-Ann Eisnor, CEO of the mapping site Platial in Portland, OR, calls "neogeography": an explosion of user-created content, such as travel photos and blog posts, pinned to specific locations *(see "Killer Maps," October 2005)*. Using Platial's map annotation software, people have created public maps full of details about everything from the history of genocide to spots for romance. Google has now built a similar annotation feature directly into Google Maps. "The idea that maps can be emotional things to interact with is fairly new," says Eisnor. "But I can imagine a time when the base map is just a frame of reference, and there is much more emphasis on the reviews, opinions, photos, and everything else that fits on top."

As these two trends continue from opposite directions, it's natural to ask what will happen when Second Life and Google Earth, or services like them, actually meet.

Because meet they will, whether or not their owners are the ones driving their integration. Both Google and Linden Lab grant access to their existing 3-D platforms through tools that let outside programmers build their own auxiliary applications, or "mashups." And many computer professionals think the idea of a "Second Earth" mashup is so cool that

The Metaverse will be accessible both in its immersive, virtual-reality form and through peepholes like the screen of your cell phone as you make your way through the real world. And like the Web today, it will become the standard way in which we think of life online.



BIG FOOT **The author inspects a live weather map built for the National Oceanic and Atmospheric Administration in Second Life.**

it's inevitable, whether or not it will offer any immediate way to make money. "As long as somebody can find some really strong personal gratification out of doing it, then there is a driver to make it happen," says Jamais Cascio, a consultant who cofounded the futurist website WorldChanging.com and helps organizations plan for technological change.

The first, relatively simple step toward a Second Earth, many observers predict, will be integrating Second Life's avatars, controls, and modeling tools into the Google Earth environment. Groups of users would then be able to walk, fly, or swim across Google's simulated landscapes and explore intricate 3-D representations of the world's most famous buildings. Google itself may or may not be considering such a project. "It's interesting, and I think there are people who want to do that," says John Hanke, director of the division of the company responsible for Google Earth. "But that's not something where we have any announcements or immediate plans to talk about it."

A second alternative would be to expand the surface area of Second Life by millions of square kilometers and model the new territory on the real earth, using the same topographical data and surface imagery contained in Google Earth. (The existing parts of Second Life could remain, perhaps as an imaginary archipelago somewhere in the Pacific.) That's a much more difficult proposition, for practical, technical reasons that I'll get to later. And in any case, Linden Lab says it's not interested.

But within 10 to 20 years—roughly the same time it took for the Web to become what it is now—something much bigger than either of these alternatives may emerge: a true Metaverse. In Neal Stephenson's 1992 novel *Snow Crash*, a classic of the dystopian "cyberpunk" genre, the Metaverse was a planet-size virtual city that could hold up to 120 million avatars, each representing someone in search of entertainment, trade, or social contact. The Metaverse that's really on the way, some experts believe, will resemble Stephenson's vision, but with many alterations. It will look like the real earth, and it will support even more users than the *Snow Crash* cyberworld, functioning as the agora, laboratory, and gateway for almost every type of information-based pursuit. It will be accessible both in its immersive, virtual-reality form and through peepholes like the screen of your cell phone as you make your way through the real world. And like the Web today, it will become "the standard way in which we think of life online," to quote from the Metaverse Roadmap, a forecast published this spring by an informal group of entrepreneurs, media producers, academics, and analysts (Cascio among them).

But don't expect it to run any more smoothly than the real world. I called programmer and 3-D modeler Alyssa LaRoche, who created the immersive weather map for NOAA, to see if she could explain that pesky blue dot over Las Vegas. As it turns out, a networking glitch was preventing the airport weather feed from reaching the map inside Second Life. And when the map doesn't get the data it's expecting, the temperature dots default to blue. So Corbin was right, in a way.

While Second Life and Google Earth are commonly mentioned as likely forebears of the Metaverse, no one thinks that Linden Lab and Google will be its lone rulers. Their two systems are interesting mainly because they already have many adherents, and because they exemplify two fundamentally different streams of technology that will be essential to the Metaverse's construction.

Second Life is a true virtual world, unconstrained by any resemblance to the real planet. What unites it and similar worlds such as There, Entropia Universe, Moove, Habbo Hotel, and Kaneva—beyond their 3-D graphics—is that they're free-flowing, ungoverned communities shaped by the shared

imaginations of their users. "Consensual hallucinations" was the term William Gibson used in his groundbreaking 1984 cyberpunk novel *Neuromancer*, which posited a Matrix-like cybersphere years before *Snow Crash*. These worlds are *not* games, however. Users don't go on quests or strive to acquire more gold or magic spells; they're far more likely to spend their time at virtual campfires, discos, and shopping malls. This sets these environments firmly apart from massively multiplayer 3-D gaming worlds such as Sony's EverQuest, Blizzard Entertainment's World of Warcraft, and NCsoft's Lineage II, which together have far more users.

Google Earth and competing programs such as Microsoft Virtual Earth, on the other hand, are more accurately described as mirror worlds—a term invented by Yale University computer scientist David Gelernter *(see "Artificial Intelligence Is Lost in the Woods," p. 62)* to denote geographically accurate, utilitarian software models of real human environments and their workings. If they were books, virtual worlds would be fiction and mirror worlds would be nonfiction. They are microcosms: reality brought down to a size at which it can be grasped, manipulated, and rearranged, like an obsessively detailed dollhouse. And they're used to keep track of the real world rather than to escape from it. Environmental scientists and sensor-net researchers, for example, are already feeding live data on climate conditions, pollution, and the like into Google Earth and Microsoft Virtual Earth, where the added spatial and geographical dimensions give extra context and help reveal hidden patterns.

It's easy to see how a detailed mirror world might bring a tactical advantage to a large corporation, government agency, or military force—for example, by making it easier for the Wal-Marts of the future to track merchandise from factory to warehouse to retail shelf, or explore what-if scenarios such as the impact of a major storm on the supply chain. But when mirror worlds are joined by a third technology stream—what's being called "mobile augmented reality"—they will become even more indispensable.

Mobile augmented reality is a way of using the data underlying mirror worlds without experiencing those worlds immersively. The extensive 3-D simulations in mirror worlds will, in the words of the Metaverse Roadmap, be draped over the real world and accessed locally in 2-D through location-aware mobile devices such as wireless phones. Even the screen of a GPS-enabled camera phone could serve as a temporary window into the Metaverse. Carry it with you on your next house-hunting expedition, for example, and it could connect to real-estate databases containing 3-D floor plans and information on sale prices, property taxes, and the like for every house on every block. Or point it at one of the turbines on your wind farm and see Google Earth's virtual version of the structure, supplemented by engineering specifications, maintenance history, and a graph of hourly power output. Finnish cell-phone giant Nokia, French startup Total Immersion, and others are building prototype augmented-reality systems now and expect the big wireless carriers to take an interest soon *(see "Augmented Reality" in "Emerging Technologies 2007," March/April)*.

It would be far too simple to say that the Metaverse will consist of Linden Lab's virtual world with maps, or Google's mirror world with avatars, or some augmented-reality slice of either one. In fact, Second Life and Google Earth are likely to endure just as they are (with the usual upgrades) well into the Metaverse era. What's coming is a larger digital environment combining elements of all these technologies—a "3-D Internet," to use the term preferred by David Rolston, CEO of Forterra Systems, a company in San Mateo, CA, that makes immersive training simulations for the U.S. Department of Defense and other first-responder agencies. People will enter this environment using PC-based software similar to the programs that already grant access to Second Life and Google Earth. These "Metaverse browsers" will be to the 3-D Internet what Mosaic and Netscape were to the dot-com revolution—tools that both provide structure (by defining what's possible) and enable infinite experimentation.

"There will be a bunch of different worlds, owned, controlled, and operated by different organizations," Rolston predicts. "They will be built on different platforms, and you will have community standards about how you can connect these worlds, and open-source software that carries you between them." The word "Metaverse" will refer to both the overarching collection of these worlds and the main port of entry to them, a sort of Grand Cyber Station that links to all other destinations. The central commons itself could be designed as a mirror world or a virtual world or some interleaving of the two: people logging in to the Metaverse might want it to look like Manhattan or the Emerald City of Oz, depending on the task at hand. But either way, partisans say, the full Metaverse will encompass thousands of individual virtual worlds *and* mirror worlds, each with its own special purpose. To borrow a trope from corporate networking, it will be an "interverse" connecting many local "intraverses."

Rolston has already had plenty of experience building such separate worlds. Some of Forterra's simulations are "geotypical"—plausible imitations of generic landscapes and urban environments—and others are "geospecific," reproducing actual places such as the entrances to Baghdad's battered Green Zone. The worlds of the Metaverse will be much more diverse but still bridgeable, Rolston predicts. "Portions of this 3-D Internet will be anchored to the real planet and will involve real-world activities, and others will not be," he says. "People will move freely between representations of the real world and representations of synthetic fantasy worlds, and feel equally comfortable in both."

For people who haven't spent much time in a 3-D world, of course, it's hard to imagine feeling comfortable in either. But such environments may soon be as unavoidable as the Web itself: according to technology research firm Gartner, current trends suggest that 80 percent of active Internet users and Fortune 500 companies will participate in Second Life or some competing virtual world by the end of 2011. And if you take a few months to explore Second Life, as I have done recently, you may begin to understand why many people have begun to think of it as a true second home—and why 3-D worlds are a better medium for many types of communication than the old 2-D Internet.

To begin with, Second Life is beautiful—wholly unlike the Metaverse one might imagine from reading *Snow Crash*. It has rolling grass-covered hills and snowy mountains, lush tropical jungles, tall pines that sway gently in the breeze, and Romanesque fountains with musically tinkling water. Linden Lab thoughtfully arranges a gorgeous golden-orange sunset every four hours.

A beautiful environment, however, isn't enough to make a virtual world compelling. Single-player puzzle worlds such as Myst provided riveting 3-D graphics as long ago as the early 1990s, but these worlds were utterly lonely, leaving users with no reason to return after all the puzzles had been solved. Part of Second Life's appeal, by contrast, is that it's always crowded with thousands of other people. If you want company, just head for a clump of green dots on the Second Life world map—that's where you'll find people gathering for concerts, lectures, competitions, shopping, museum-going, and dancing. "Second Life is best viewed as a communication technology, just like the telephone," says Cory Ondrejka, Linden Lab's chief technology officer. "Except that you don't communicate by voice; you communicate by shared experience." And unlike the telephone system, Second Life is free (unless you want to own land, which means upgrading to premium membership for $9.95 per month).

Second Life residents also communicate through the buildings and other objects they create. Using built-in 3-D modeling tools, any resident can create something simple, like a flowerpot or a crude hut. But the revered wizards of the community are those who can quickly conjure basic building blocks called "prims" and reshape and combine them into complex objects, from charm bracelets and evening gowns to airplanes and office buildings. Alyssa LaRoche, creator of the NOAA weather map, is one of these builder-wizards. She started creating things as soon as she joined Second Life in January 2004, and by April 2006 she had quit her day job as an IT consultant in the financial-services industry to start a Second Life design agency called Aimee Weber Studio (after her avatar's name). Business has been so brisk that LaRoche now employs four other full-time modelers and 19 contractors. "I'm certainly making more money than I made at my job as a consultant," she says. Her agency recently finished an entire island of oceanographic and meteorological exhibits for NOAA, including a glacier, a submarine tour of a tropical reef, and an airplane ride through a hurricane.

NOAA commissioned its island as a kind of educational amusement park, a Weather World. But other parts of Second Life are more businesslike. Dozens of companies, including IBM, Sony Ericsson, and American Apparel, have bought land in the virtual world, and most have already built storefronts or headquarters where their employees' avatars can do business. In March, for example, Coldwell Banker opened a Second Life real-estate brokerage where new residents can tour model virtual homes and make purchases at below-market rates. In 2006, Starwood Hotels used Second Life as a virtual testing ground for a new chain of real-world hotels, called Aloft. The company constructed a prototype where visitors could walk the grounds, swim in the pool, relax in the lobby, and inspect the guest rooms. It's incorporating suggestions from Second Lifers into the design of the first real Aloft hotel, set to open in Rancho Cucamonga, CA, in 2008.

It would be far too simple to say that the Metaverse will consist of Linden Lab's virtual world with maps or Google's mirror world with avatars. What's coming is a larger digital environment combining elements of all these technologies—a 3-D Internet.

Most structures in the Second Life universe, of course, lack any serious business purpose. But that doesn't mean they have no relation to the real world. One of Second Life's most trafficked places is a detailed re-creation of downtown Dublin. The main draw: the Blarney Stone Irish pub, where there is live music most nights, piped in from real performance spaces via the Internet. A short teleport-hop away from virtual Dublin is virtual Amsterdam, where the canals, the houseboats, and even the alleyways of the red-light district have been textured with photographs from the real Amsterdam to lend authenticity.

This reimagining of the real world can go only so far, given current limitations on the growth of Linden Lab's server farm, the amount of bandwidth available to stream

data to users, and the power of the graphics card in the average PC. According to Ondrejka, Linden Lab must purchase and install more than 120 servers every week to keep up with all the new members pouring into Second Life, who increase the computational load by creating new objects and demanding their own slices of land. Each server at Linden Lab supports one to four "regions," 65,536-square-meter chunks of the Second Life environment—establishing the base topography, storing and rendering all inanimate objects, animating avatars, running scripts, and the like. This architecture is what makes it next to impossible to imagine re-creating a full-scale earth within Second Life, even at a low level of detail. At one region per server, simulating just the 29.2 percent of the planet's surface that's dry land would require 2.3 billion servers and 150 dedicated nuclear power plants to keep them running. It's the kind of system that "doesn't scale well," to use the jargon of information technology.

But then, Linden Lab's engineers never designed Second Life's back end to scale that way. Says Ondrejka, "We're not interested in 100 percent veracity or a true representation of static reality."

And they don't have to be. As it turns out, simulations need not be convincing to be enveloping. "It's not an issue of engaging the eyes and the hands, but rather of engaging the heart and the mind," says Corey Bridges, executive producer at the Multiverse Network, which sells a standardized virtual-world platform that developers can tailor to their own needs. "If you can form a connection with someone, even just with a mouse and a keyboard and a video screen, whether it's in Second Life or World of Warcraft, that is far more powerful than even the best virtual-reality simulation."

Personal connections may be what a lot of people want, but going by the numbers, Google Earth is far more popular than any other type of virtual world, including the big role-playing worlds like Lineage II (which has 14 million subscribers) and World of Warcraft (more than 8 million). By the spring of 2007, less than two years after it was launched, Google Earth had already been downloaded more than 250 million times.

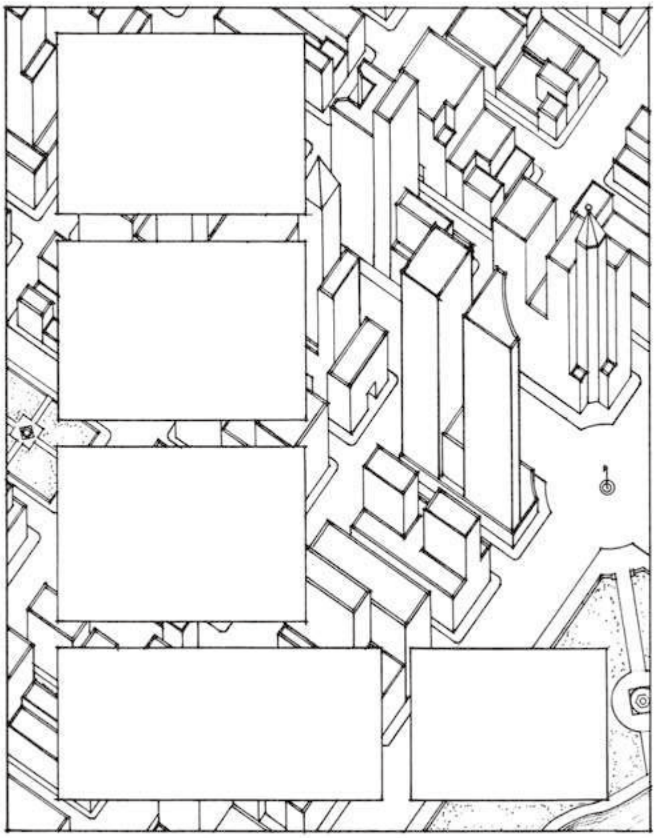
Google Earth and its lesser-known imitator, Microsoft Virtual Earth, owe their existence to a convergence in the early 2000s of several trends, including a drop in the price of satellite and aerial imagery, the more widespread availability of topographical and other geographical information collected by national governments around the world, the standardization of 3-D modeling technologies originally developed for video games, and the spread of consumer PCs with graphics cards capable of 3-D hardware acceleration. But the programs' philosophical roots go back much further than that. John Hanke, who developed the original software behind Google Earth at a small company called Keyhole (which Google acquired in 2004), says that *Snow Crash*'s description of a 3-D program called Earth—"a globe about the size of a grapefruit, a perfectly detailed rendition of Planet Earth"—was part of his inspiration.

An equally detailed vision of a virtual earth was laid out in another book from the same era, David Gelernter's *Mirror Worlds: Or the Day Software Puts the Universe in a Shoebox … How It Will Happen and What It Will Mean*. "The software model of your city, once it's set up, will be available (like a public park) to however many people are interested," Gelernter predicted. "It will sustain a million different views. … Each visitor will zoom in and pan around and roam through the model as he chooses." Institutions such as universities and city governments would nourish the mirror world with a constant flow of data. The latest information on traffic jams, stock prices, or water quality would appear exactly where expected—overlaid on virtual roads and stock exchanges and water mains. But just as important, mirror worlds would function as social spaces, where people seeking similar information would frequently cross paths and share ideas. They would be "beer halls and grand piazzas, natural gathering places for information hunters and insight searchers."

David Gelernter's *Mirror Worlds* laid out a detailed vision of a virtual earth: "The software model of your city, once it's set up, will be available ... to however many people are interested. ... Each visitor will zoom in and pan around and roam through the model as he chooses."

On page 203 of *Mirror Worlds* is a striking architectural drawing showing a bird's-eye view of a fictional city distinguished by elegant skyscrapers, broad avenues, and abundant parkland. Superimposed on the view are several blank white boxes where, in Gelernter's hypothetical mirror world, information about the streets and buildings would be displayed. The caption describes the drawing as "an abstract sketch, merely the general idea" of what a mirror-world interface might look like.

If the sketch looks familiar today, it's because thousands of views like it can be found using Google Earth or Microsoft Virtual Earth, complete with 3-D buildings and white



DÉJÀ VU **A sketch from David Gelernter's 1991 book *Mirror Worlds* shows what he thought a future data world might look like. It strongly resembles a city in today's Google Earth.**

COURTESY OF DAVID GELERNTER

pop-up info boxes. There are superficial differences: the Google and Microsoft cityscapes, for example, are photo-realistic, at least in the limited areas where buildings are covered with "skins" based on photographs of the real structures (like the virtual Amsterdam in Second Life). But Gelernter anticipated so many features of today's virtual-globe software that these programs could readily serve today as the windows on a mirror world as he imagined it. In fact, Google Earth users can access a growing library of public and personal data, from national borders to Starbucks locations, jogging routes, and vacation photos—in effect, any kind of information that's been "geocoded."

Open geocoding standards allow anyone to contribute to the Google Earth mirror world. Just as Web browsers depend on HTML to figure out how and where to display text and images on a Web page, Google Earth depends on a standard called KML, the keyhole markup language, to tell it where geographic data should be placed on the underlying latitude-longitude grid. If you know how to assemble a KML file, you can make your own geographical data appear as a new "layer" on your computer's copy of Google Earth; and if you publish that KML file on the Web, other people can download the layer and display it on their own computers.

This layering capability transforms Google Earth from a mere digital globe into something more like a 3-D Wikipedia of the planet. The results can be unexpectedly arresting. In one recent example, the U.S. Holocaust Memorial Museum worked with Google to create a layer highlighting the locations of 1,600 villages ravaged by the Sudanese government's ongoing campaign to wipe out non-Arab tribes in the Darfur region. By zooming in on these locations, a user can see the remnants of the actual settlements destroyed by the Janjaweed, the government's proxy militia. The closest views reveal that house after house has been reduced to a crumbling wreck—roofs burned away, contents apparently looted. Pop-up boxes contain testimony from survivors, statistics on the displaced populations, and dramatic, often grisly photographs taken in the field or at refugee camps.

This evidence of genocide is attached to the same digital earth where most U.S. residents can quickly zoom and pan to North America and look down upon their own houses or their children's schools. With the barrier of distance dissolved, it's hard not to feel a greater sense of connectedness to tragedies abroad. Which is exactly what the Holocaust museum intends: "We hope this important initiative with Google will make it that much harder for the world to ignore those who need us the most," museum director Sara Bloomfield said. (The Sudanese themselves cannot download Google Earth, owing to U.S. restrictions on software exports.)

Just as anyone can create a new layer for Google Earth, anyone with basic 3-D modeling skills can add buildings, bridges, and other objects to it. Google Earth uses the open Collada 3-D modeling format, which was originally created by Sony as a way to speed the development of video-game worlds for the PlayStation Portable and the PlayStation 3. Using a Google program called SketchUp, amateur architects have built thousands of Collada models and uploaded them to the Google 3D Warehouse, a free library of signature buildings and other 3-D models. Larger organizations around the world now have terabytes of Collada-formatted virtual objects in storage and can easily transform them into data layers for Google Earth. That's what the city government of Berlin did in March, when it published a KML layer containing a meticulous 3-D model of the city, prepared as part of a new digital infrastructure for city management and economic development. The model is so finely detailed that a deft user of the Google Earth navigation controls can steer the camera through the front door of the newly renovated Reichstag and into the chambers of the German parliament.

But a true mirror world shouldn't be static, as the Berlin model and the Darfur layer are; it should reflect all the hubbub of the real world, in real time. As it turns out, KML also supports direct, real-time exchanges over the Internet using the hypertext transfer protocol (HTTP), the basic communications protocol of the Web. One hypnotic example is the

ACHTUNG, BABY **With Google Earth, it is now possible to zoom inside Berlin's Reichstag building.**

3-D flight tracker developed by Fboweb.com, a company that offers online flight-planning tools for general-aviation pilots and enthusiasts. Download the KML layer for one of the eight major U.S. airports that Fboweb covers so far, and tiny airplane icons representing all the commercial aircraft heading toward that airport at that moment will be displayed at the appropriate altitude in Google Earth. As time passes, each flight leaves a purple trail recording every ascent, turn, and descent, all the way down to the runway. It's a plane-spotter's dream.

Microsoft, as one might expect, isn't far behind Google in its effort to bridge map worlds and the real world. Scientists at Microsoft Research are perfecting a system called SensorMap that collects live data from any location and publishes it in Windows Live Local (the latest name for Microsoft's online 2-D maps) or Microsoft Virtual Earth. Researchers at Harvard University and BBN Technologies in Cambridge, MA, won a grant from Microsoft this spring to create a SensorMap interface for "CitySense," a network of 100 Wi-Fi-connected weather and pollution sensors they're installing in Cambridge. Other scientists, however, are already using Google Earth to monitor live sensor networks. At the Center for Embedded Networked Sensing at the University of California, Los Angeles, researchers have connected a network of wireless climate sensors and webcams in the James Reserve, a wilderness area in California's San Jacinto Mountains, to a public KML layer in Google Earth. Click on an icon in Google Earth representing one of the reserve's nest boxes, and you get a readout of the temperature and humidity inside the nest, as well as a live webcam picture showing whether any birds are at home.

"Google Earth itself is really neat," comments Jamais Cascio, the Metaverse Roadmap coauthor. "But Google Earth coupled with millions of sensors around the world, offering you real-time visuals, real-time atmospheric data, and so on—that's transformative."

Indeed, it's important to remember that alongside the construction of the Metaverse, a complementary and equally ambitious infrastructure project is under way. It's the wiring of the entire world, without the wires: tiny radio-connected sensor chips are being attached to everything worth monitoring, including bridges, ventilation systems, light fixtures, mousetraps, shipping pallets, battlefield equipment, even the human body. To be of any use, the vast amounts of data these sensors generate must be organized and displayed in forms that diagnosticians or decision makers can understand; "reality mining" is the term researchers from Accenture Technology Labs, the MIT Media Lab, and other organizations are using for this emerging specialty. And what better place to mine reality than in virtual space, where getting underneath, around, and inside data-rich representations of real-world objects is effortless?

In the field, technicians or soldiers may get 2-D slices of the most critical information through wireless handheld devices or heads-up displays; in operations centers, managers or military commanders will dive into full 3-D sensoriums to visualize their domains. "Augmented reality and sensor nets will blend right into virtual worlds," predicts Linden Lab's Ondrejka. "That's when the line between the real world and its virtual representations will start blurring."

I asked David Gelernter why we'd need the Metaverse or even mirror worlds, with all the added complications of navigating in three dimensions, when the time-tested format of the flat page has brought us so far on the Web. "That's exactly like asking why we need Web browsers when we already have Gopher, or why we need Fortran when assembly language works perfectly well," he replied.

The current Web might be capable of presenting all the real-time spatial data expected to flow into the Metaverse, Gelernter elaborates, but it wouldn't be pretty. And it would keep us locked into a painfully mixed and inaccurate metaphor for our information environment—with "pages" that we "mark up" and collect into "sites" that we "go to" by means of a "locator" (the *L* in URL)—when a much more natural one is available. "The perception of the Web as geography is meaningless—it's a random graph," Gelernter says. "But I know my physical surroundings. I have a general feel for the world. This is what humans are built for, and this is the way they will want to deal with their computers."

Judging by the growing market for location-aware technologies like GPS cell phones, the popularity of map-based storytelling and neogeography mashups like Platial, and the blistering pace of Google Earth downloads, Gelernter may be right. Google Earth is now so well known that it has been satirized on *The Simpsons* and is becoming a forum for classified ads and résumés. Second Life, meanwhile, is gaining roughly 25,000 members a day, sometimes stretching Linden Lab's ability to keep its simulations running smoothly.

But for a true Metaverse to emerge, programmers must begin to weave together the technologies of social virtual worlds and mirror worlds. That would be a simpler task if Google and Linden Lab would release the source code behind their respective platforms, or at least provide application programming interfaces (APIs) so that outside developers could tap into their deeper functions. In late 2006, Google released an interface that allowed outside programmers to control some aspects of Google Earth's behavior, but it wasn't a full API, and there's been no sign of one since. This January, Linden Lab released the source code for the Second Life viewer (the program that residents use on their PCs to connect to Second Life). Ondrejka says the code for the core Second Life simulation software will follow. First, he says, the company needs to get that software working better—and figure out how to make money in a world where it may no longer control the expansion of the Second Life ecosystem.

The real progress toward a fusion of Second Life and Google Earth is going on outside their home companies. Last year, Andrew "Roo" Reynolds, a "Metaverse evangelist" at IBM's Hursley laboratory in England, hacked together an extension for SketchUp that turns Collada 3-D models into prim-based objects in Second Life. And while it may be impractical to make Second Life into a walkable Google Earth, Daden, a company in Birmingham, England, is bringing Google Earth into Second Life. The result isn't exactly a globe, however. It's a *virtual* virtual-reality chamber where the Google Earth continents are displayed as if pasted to the inside of a giant sphere, with the user's avatar at the center. Clickable "hot spots" bring up real-time earthquake data and news feeds from CNN, the BBC, and the *Indian Times*.

No one knows yet how to bring Second Life–like avatars directly into Google Earth, but researchers at Intel have demonstrated one possible approach. In late 2006, they created a primitive video game, called Mars Sucks, that challenges Google Earth users to search out and destroy Martian invaders using clues to the locations of their spaceships. The core of the game is a KML layer with special scripts that communicate with both the usual Google Earth content servers and a separate game server that controls elements such as the clues, cockpit graphics, and explosions. Using the same technique, it might be possible to superimpose avatars on the Google Earth environment without having to change anything about the program itself.

Avatars of a sort can already travel through Google Earth thanks to Unype, a mashup using the free voice-over-IP pro-

To read an expanded version of this story, with links to many odd corners of Second Life and Google Earth, please visit **technologyreview.com/secondearth**.

gram Skype. Developed by New York software consultant Murat Aktihanoglu, Unype helps geography hounds logged in to Skype synchronize their copies of Google Earth so that they're viewing the same locations and layers. Unype can insert crude, nonanimated avatars, which the users can build themselves in the Collada format. "I don't think it's the ultimate realization of the Metaverse vision," says Google's Hanke. "It's interesting to see people trying to bring these threads together."

From these threads, indeed, an entire tapestry of 3-D services is faintly taking shape. The mature Metaverse won't have a single killer app, say Gelernter and other observers, any more than the Web does.

Certainly, it will enable new kinds of data analysis and remote collaboration, with potentially life-saving results. "As soon as you look at the NOAA weather map in Second Life, you say, 'Okay, what if we did the same thing using flu pandemic data?'" says Ondrejka. "You could get together the CDC and the country's 50 leading epidemiologists, and they could have their huge supercomputer-driven infection model running. They'd get insights they couldn't get just by reading reports." It's not an outlandish scenario: epidemiology has already come to Google Earth, courtesy of systems-biology graduate student Andrew Hill and colleagues at the University of Colorado, who published a KML file in April with a grim animated time line showing how the most virulent strains of avian flu jumped from species to species and country to country between 1996 and 2006.

Virtual tourism is another application whose audience seems certain to expand. Already, the National Geographic and Discovery networks offer Google Earth layers pegging multimedia files to exotic locations such as the Gombe forest in Tanzania, where researchers at the Jane Goodall Institute continue to study colonies of chimpanzees. More is possible. "What I want to do one day is represent the Grand Canyon or a national park with such fidelity that you could essentially go there and plan your whole trip," says Michael Wilson, CEO of Makena Technologies, the company that operates the virtual world There. "Or what if you could model a Europe where the sea level is 10 feet higher than it is today, or walk around the Alaskan north and see the glaciers and the Bering Strait the way they were 10 years ago? Then perceptions around global warming might change."

Such possibilities are uplifting, to be sure, but the hard-nosed truth is that we don't need a Stephensonian Metaverse to make them happen. Remote collaboration, virtual tourism, shopping, education, training, and the like are already common on the Web, a vast resource that grows faster than we can figure out how to use it. Digital globes are gaining in fidelity, as cities are filled out with 3-D models and old satellite imagery is gradually replaced by newer high-resolution shots. And today's island virtual worlds will only get better, with more-realistic avatars and settings and stronger connections to outside reality. A fully articulated Metaverse, whether it's more like *Snow Crash* or Second Life, would undeniably be overkill.

But many people feel a pull toward the Metaverse dream that defies practical logic. To illustrate, Will Harvey, the creator of There, tells a story about water.

Liquid, running, rippling water was one of the features he and his team badly wanted to include in There. "Every employee of the company understood that water was an essential component that made a landscape feel like a real place," Harvey says. And when arch rival Second Life launched a few months before There in 2003, it was soaking in animated H_2O, from waterfalls to fountains to the vast ocean surrounding its continents. "It became a standing joke that we desperately needed water," Harvey continues. "But the business side of the company understood, correctly, that water wasn't necessary to solve the problem of creating a place for people to socialize."

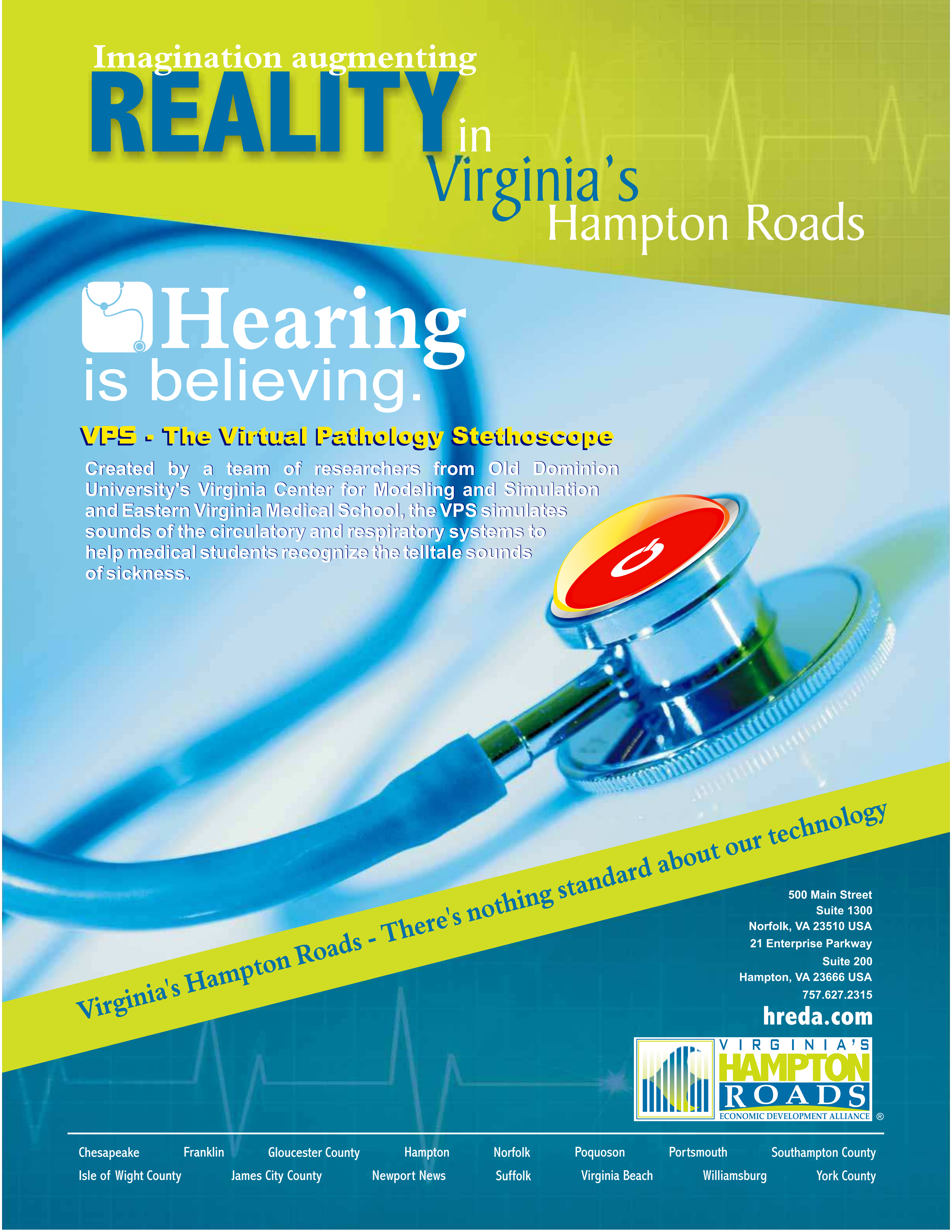
The argument wore on for months. In the end, There got water, but it was motionless and impenetrable—"like blue cement," Harvey says scowlingly.

The point, says Harvey, is that "if you trim the technology down to the features you really need in order to solve a problem, you end up with something that's a lot less than the Metaverse. But deep inside me and inside all of the people running There or Second Life is a desire to build this incredibly fascinating, incredibly rich version of the Metaverse, the one that has been the vision of science fiction authors for 30 years and of computer engineers for 20."

I have come to understand this desire. In the course of my research for this story, I bought land in Second Life, built a house, filled it with furniture, bought and razed the adjoining land, lifted my house a hundred meters into the sky to get it out of the way, and began work on a bigger house. I was also befriended by dozens of Second Life residents, several of whom I now know better than my real neighbors. Most were delighted to hear about my story, to tell me how they're spending their second lives, and to show me their own creations, including a hot-dog-shaped airplane and an animated Tibetan prayer wheel.

This, then, is how the Metaverse will take shape: through the imaginations of the programmers, merchants, artists, activists, and networkers who are already moving there. If these part-time émigrés from reality want embellishments like running water or six sunsets a day, they'll code their universes that way. The rest of us may smile at their whimsy—but we will take up, and come to depend upon, the serious tools that underlie their play. And if the world we create together is less lonely and less unpredictable than the one we have now, we'll have made a good start. TR

Wade Roush is a Technology Review *contributing editor.*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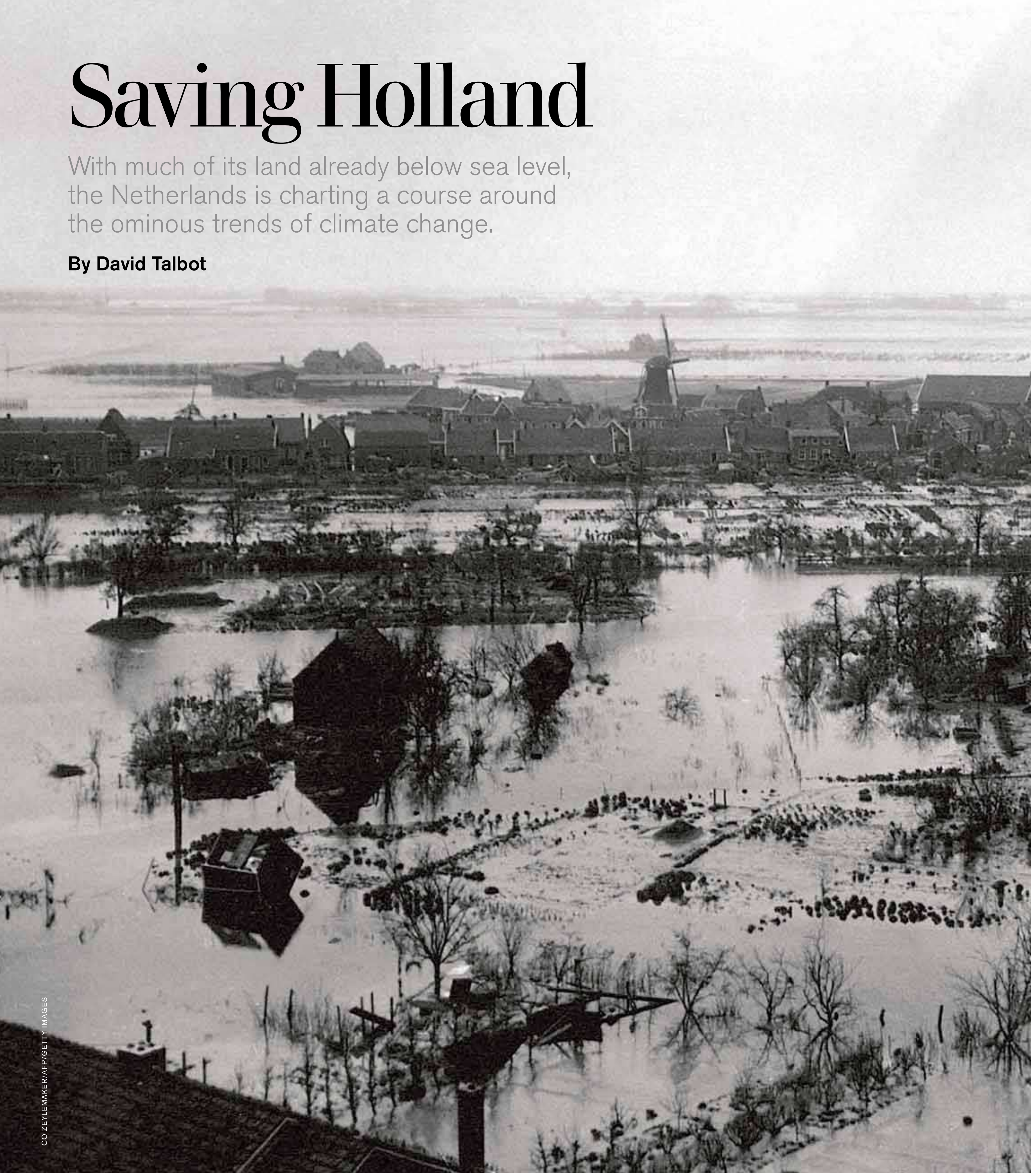
Saving Holland

With much of its land already below sea level, the Netherlands is charting a course around the ominous trends of climate change.

By David Talbot



CO ZEYLEMAKER/AFP/GETTY IMAGES

NEVER AGAIN: A deadly 1953 flood prompted a massive Dutch effort to build seawalls and surge barriers. Climate change is prompting a new shift, toward intensive flood-risk analysis and resilient construction.

The lowest point in western Europe is 6.74 meters below sea level and falling. It lies in a boggy area of decomposing peat outside the cheese mecca of Gouda, the Netherlands, and is identified by a seven-meter marker plunked into a brackish pool at the entrance to the Van Vliet truck dealership. (The dealership's owner erected the marker, taking a little license with the facts; the actual low spot is a few hundred meters away.) The Fodor's travel guide does not mention this corner of Holland, but it's a focal point for the question of how to plan for the risks and realities of climate change.

That's because the town of Gouda is considering whether to erect 4,000 houses—some of which might float—just two kilometers from this continental nadir. Subdivisions may rise on portions of the sparsely developed farmland near the truck dealership, a 50-square-kilometer area surrounded by dikes and a canal. Such reclaimed lowlands are called polders; they're kept dry by pump houses that suck away rainwater and groundwater seepage. The Dutch have always built on polders, but doing so now, as flood risks rise across the country, will require new approaches that could get an early test in this particularly low region, called the southwest polder or Zuidplaspolder. "It sounds, sometimes, somewhat illogical," concedes Marco van Steekelenburg, an urban planner with the regional province of South Holland, who took me to the site. "But that is what we have to investigate: how illogical it is. We have been given a challenge: can we find solutions which are climate-proof?"

The country faces ominous trends as global temperatures rise. Already, 55 percent of the Netherlands' land area is below sea level, protected by a vast system of seawalls, storm-surge barriers, and thousands of dikes that crisscross the countryside. Dutch scientists say sea levels in the region will rise between 25 and 85 centimeters (10 and 33 inches) this century. In addition, weather worldwide is expected to become more extreme, on average. This means a higher likelihood of flooding along the Rhine and other rivers, and a greater risk of droughts. All the while, Dutch land will continue to sink—at a rate of 0.2 centimeters annually in some areas—as the peat soil underlying much of it decomposes, exposed to air by Dutch drainage efforts.

Now, in an effort being watched around the world, the Dutch government and several prominent research institutions are trying to figure out how to adapt a whole country to the realities of climate change. The Zuidplaspolder is one of several regions under consideration for developments that float—or *can* float, or at least are flood resistant. Apart from

Note from the editor: *This is* Technology Review*'s second feature examining plans for adapting to radical climate change. In our May/June issue, we described how U.S. institutions are revisiting urban storm-surge risk assessments and making fine-scale predictions about how disappearing mountain snowpack could devastate water supplies.*

WATER WORLD **Prototype "amphibious" houses (below) flank a marina in rural Maasbommel. One such house (left) can rise four meters, guided by pilings (bottom left). Similar concepts await implementation until a national climate adaptation plan is complete.**

SIEBE SWART

one well-hyped residential demonstration project elsewhere in the country, though, no actual construction has yet begun. Behind the scenes, the Dutch are taking a hard look at their growing vulnerabilities, conducting new analyses and running computer simulations. The researchers hope to submit a plan for adapting to climate change to the Dutch parliament this fall and to take action on it by next year.

It's all about understanding risk. This means understanding exactly how breaches in dikes and seawalls could lead to flooding in farms and cities—how deep the waters could get and how fast they might rise. It means understanding how those risks will change under various conditions, such as higher sea levels and different weather patterns. It means calculating how many people and how much property lie in the path of such floods, and how future changes in land use could worsen or mitigate any damage. Once they understand all that, the Dutch can plan, build, and fortify in ways that meet specific local needs. This could mean designating certain areas as no-build zones, developing new building techniques, adding floatable roadways as escape routes, or replacing farms with floating greenhouses. All this represents a major shift in focus, from preventing floods to minimizing damage when they occur. "You are looking at a different type of planning," says Pieter Bloemen, a program manager with the Netherlands' National Spatial Planning Agency.

Historically, the Netherlands—like most other countries—has thought about disaster protection in simple but reassuring terms. The Netherlands' North Sea flank is sheltered by great seawalls and tidal-surge barriers erected after a 1953 flood that killed nearly 2,000 people. The strongest of these were engineered to withstand all but the rarest disasters: floods that have only a 1-in-4,000 chance—even a 1-in-10,000 chance—of happening in a given year. But these probabilities were calculated around 1960 and are understood to be obsolete. What's more, the Dutch population surged from 11.5 million in 1960 to 16.6 million this year, greatly raising the stakes. "Most people in the Netherlands have the idea they are safe from flooding, because of all the investment," says Hans Balfoort, a senior policy advisor in the Netherlands' Ministry of Transport, Public Works, and

Water Management in The Hague. "It gives people a false idea of absolute protection."

The Dutch program for intensive risk analysis and planning is gaining attention in geographically similar parts of the world, including the Mississippi River Delta in Louisiana and the Sacramento River Delta in California. "There is a lot of pressure that places like New Orleans should adopt this kind of approach for planning and protection," says Rafael Bras, a hydroclimatologist at MIT. He notes that in the U.S., as in the Netherlands, planners and engineers have historically focused on the strength of seawalls and levees, not the extent of the destruction that could occur if they failed. "In the past, our approach has been, 'We will protect to a certain-level hurricane,' without trying to translate that into, 'What does that mean in terms of risk to the population?'"

Dams of Rotterdam

The risk analysis the Dutch are performing requires basic information about the country's network of seawalls and dikes, but collecting it is no easy task. Much of the nation was reclaimed from the sea piecemeal over the past 800 years: farmers drained land, dug canals, and built dikes, giving rise to the saying "God made the world, but the Dutch made the Netherlands." Local democratic bodies called water boards—hundreds of them—emerged to manage and maintain flood barriers and pumping stations. But the accretion of locally built fortifications did not leave a legacy of centralized, accurate records. "We are not Swiss," laments Jaap Kwadijk, a geologist with the engineering firm Delft Hydraulics.

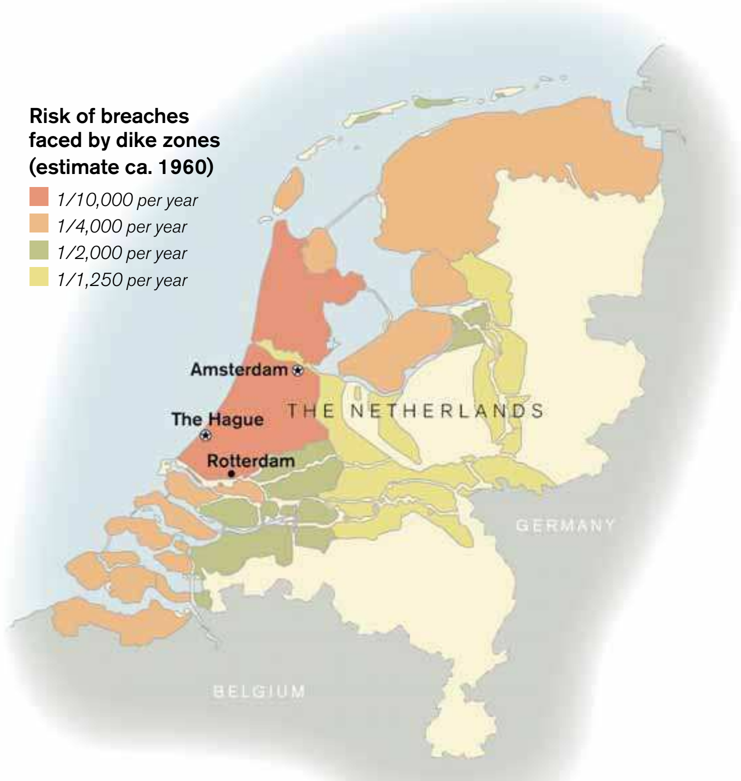
To understand how un-Swiss the Dutch are, consider the political history of the southwest polder, the area near Gouda where the 4,000 houses may rise. Historically, a chunk of the polder was managed by a water board called the Schieland, organized in 1273. An adjacent water board, the Krimpenerwaard, was founded in the 1430s, cobbled together from smaller boards. Dramatic change came in 2005. After 535 years of peaceful coexistence, the Krimpenerwaard joined with the Schieland. The merger is marked by a prominent sign inside the region's biggest pump house, designating the board the "Hoogheemraadschap van Schieland en de

Krimpenerwaard." Pump-house engineer Harry Berkouwer, whose family has lived for more than 600 years in the hamlet of Berkenwoude (its name means "birch forest"; his means "birch cutter"), beams when he speaks of the event.

Despite such mergers, there are still 27 separate water boards in a country that's only about twice the size of New Jersey. And the hodgepodge of record-keeping makes painstaking work for engineers like Arthur Mynett, director of research and development at Delft Hydraulics and an engineering professor at the Delft University of Technology. His group is probing for potential failure points in existing Dutch dikes; that requires knowing the precise height and engineering characteristics of every one of them. "We are trying to integrate everything," Mynett says. "If one of these dikes goes, collapses, that has an effect on the probability that others will go. Some might have a higher, others might have a lower probability. It is not that trivial to find out. From history, the Netherlands is a country which is also separated in rather small administrative units—not only the water boards, but municipalities and railroads. All these organizations have their own databases. It's already quite an effort, let's say, that you can even use it all."

But his group is making progress; it is now running simulations to show how floodwater could cascade from polder to polder, farm to farm, and street to street under various failure scenarios. Nathalie Asselman, a staff hydrologist at Delft Hydraulics, gave me a demonstration with a few clicks of a mouse. On her computer flashed a map of the city of Rotterdam. She ran a recently created model of two possible disasters. In the first, a major levee failed, and blue, representing water, rapidly filled an empty area impounded by a second levee. From there, various shades of blue—indicating different depths—trickled out slowly to parts of the city, rising to a height of about a meter over several days. That would be serious, but not life-threatening or city-wrecking. Then Asselman showed what would happen if the second levee weren't there and a major storm-surge barrier several kilometers away were left open. What unfolded would, if it happened in real life, dwarf the New Orleans catastrophe. In a matter of hours, much of Rotterdam was awash in blues, with flooding as high as three meters in some areas.

That the Dutch haven't previously tried to understand the consequences of calamities in such detail points to the irony of having strong defenses. No catastrophic flood has befallen the nation since 1953. That freedom from disaster has bred complacency. "Sometimes a plane falls down and you can investigate why it falls down," says Kwadijk. "The trouble is, we never get any flooding, so you can't test anything, and you can't convince the public [of the danger]." But all that changed in 2005, when the Dutch were transfixed by the destruction in New Orleans following Hurricane Katrina. "Katrina raised awareness in the Netherlands," says Mynett.



CAROL ZUBER-MALLISON

Reassessing Risk

The Dutch dike system was tailored to flood probabilities calculated around 1960. Faced with climate change and population growth, the Dutch are now seeking systemic forms of protection, from upstream water impoundments to floatable buildings and roadways.

"To the general public, it wasn't, 'Silly Americans can't take care of water management.' It was, 'Oops—this can happen.' It is more a feeling of solidarity."

Modeling the Rhine

Pinpointing weaknesses in existing water barriers is just a first step toward understanding the Netherlands' flood risk. Rising sea level is, of course, the elephant in the room. But for the moment, the elephant is moving slowly enough to rank lower on the list of Dutch concerns than certain near-term threats. One is that the Rhine could burst its banks in areas such as Rotterdam. And as peat decomposes, land is sinking faster than the sea is rising. (To make matters worse, peat decomposition, triggered by centuries of Dutch land drainage, throws off greenhouse gases.) Finally, new roads and developments could increase runoff, and population growth could put more people in the path of disaster.

At Wageningen University's Alterra research institute, 20 earth scientists and climate scientists are trying, among other things, to develop an accurate way of forecasting the water level of the Rhine. The goal is to understand the entire river as a system, from its headwaters in the Swiss Alps, through Germany, and finally through Rotterdam to the North Sea—to figure out how much precipitation it receives, what hydrological processes shape it and its watershed, and

how development will change these factors. The Alterra group is trying to integrate meteorological and hydrological models and use them to evaluate various scenarios of climate and land-use change. "All the different components of the model are available somewhere," says Eddy Moors, a hydrometeorologist at Alterra. "There's a Dutch model, a German model, a hydrological model, a meteorological model. It's a matter of finding a way to combine those components, more than inventing something new."

One of the factors the researchers are considering is that radical changes are expected in European land use. Dutch planners say that by 2050, European agricultural land totaling an area larger than Germany will give way to development or, in some cases, revert to forest. That, in turn, will affect the way floods propagate—by altering the ability of the land to absorb water, for example. "If we take these changes into account and look into land use, we can perhaps promote some land-use changes which will assist us," says Moors. "We want to see the feedback of those changes." As part of his study, Moors has even been investigating how trends in land use might change the local weather. By running meteorological models, he found that turning farmland into forest is likely to stimulate more local precipitation. Whether this is good or bad depends on whether it happens during a summer drought or a winter flood. Either way, analyzing such effects is important to understanding the larger system.

"Katrina raised awareness in the Netherlands. To the general public, it wasn't, 'Silly Americans can't take care of water management.' It was, 'Oops—this can happen' ... a feeling of solidarity."

In addition to forecasting the effects of changing land use, the Alterra group is trying to predict the effects of intensified weather extremes. The Intergovernmental Panel on Climate Change, the U.N.-sponsored body whose work represents the global scientific consensus on the subject, recently predicted that warmer temperatures worldwide could make droughts harsher and precipitation more intense. And in winter, precipitation will tend to fall more as rain than snow in some areas, including the Swiss Alps, at the Rhine's headwaters. As a result, wintertime river flooding—already a problem in the Netherlands—could get far worse. Buffer systems of some kind will probably be required. These might be impoundment areas upriver, perhaps even in Germany, or underground tanks beneath Dutch developments. But planners need to know where to put these buffer systems, and how to manage them so they're empty when deluges are expected but full when droughts are near. This calls for better long-range forecasts. "To adapt, it is important to have forecasting systems," says Moors. "To be able to do that, you have to couple meteorology and hydrology models."

Developing these sharper predictive tools is a pursuit common to planners in The Hague, New York City, and California *(see "Planning for a Climate-Changed World," May/June)*. But in the Netherlands, the need is acute. "Our whole country is at stake," says Piet Dircke, director of the water program at Arcadis, an engineering and consulting firm based in Maastricht that is participating in national planning efforts. "So we are moving from an engineering kind of approach to a systems approach. You never know which part is going to change, and which one will be relevant, until you look at the complete system."

To experience historical and possible future flooding in the Netherlands, visit **technologyreview.com/holland.**

Floating Houses

Once the risk analysis is complete, it will help guide decisions on where and how to build. Development is already restricted in some stretches of river floodplains and may soon be in others. But with population continuing to rise, there's great pressure to develop tracts of low-lying areas like those in the southwest polder. And besides, defying the sea is a point of patriotic pride. "It is our culture to cope with water," says Chris Zevenbergen, director of business development at the construction company Dura Vermeer and a professor at the Unesco-IHE Institute for Water Education in Delft. "Retreat would give a very bad signal to the world. Suppose we are not building; this will have an enormous impact on the climate for foreign investment. And from a technological point of view, [construction] is feasible. We need to adapt to that kind of development."

To demonstrate what is possible, Dura Vermeer has built a floating housing development in a hamlet called Maasbommel, in the rural province of Gelderland, near the center of the country. There, 46 amphibious houses are perched on the outer edge of a dike that holds back the River Maas, adjacent to a marina. Sixteen are floating at the river's edge, in conjoined pairs, with sealed hollow basements providing buoyancy. Between each pair of houses are two vertical concrete piles; if water levels rise, the houses rise around the piles. Flexible water, sewer, and electrical connections are unaffected. Thirty similar houses sit on slightly higher ground, on concrete slabs a meter or so above the waterline. They, too, have piles and hollow basements that

HIGH AND DRY CONCEPT **A developer's vision of a floating town, complete with greenhouses, is still just a vision. The Dutch are doing risk analyses to decide where to build, where to forbid development, and where to change construction techniques.**

will let them float if necessary. All 46 houses can tolerate a four-meter rise in water levels. Though the houses have been finished since 2006, the higher ones have not yet faced a flood high enough to test them. "Everybody wants to see it happen. Including the builder and the architect," jokes Cees Westdijk, who owns one of the houses. His two-bedroom house offers beautiful water views; on the downside, an algae bloom last year made for a nasty, if temporary, smell.

The Netherlands has designated 15 areas near riverbeds as possible sites for amphibious developments, including variations on the Maasbommel prototype. For the southwest polder, researchers at Delft Hydraulics and Wageningen University have already produced the first risk maps, showing which areas within its 50 square kilometers are most vulnerable. National planners "look inside the dike ring and make zones for how the water comes—fast and deep, fast and undeep, slow," says Bloemen of the National Spatial Planning Agency. Buildings could be customized accordingly; some might always float, others might rise and fall if needed, and still others might simply be built to survive inundation without sustaining major damage. "You [could] have building restrictions appropriate to the relative dangers and flooding probabilities within each subzone," Bloemen says.

For the southwest polder, university and government researchers are considering what kinds of development might be suitable. One option is to raise water or ground levels in parts of the polder and build amphibious or floating structures as appropriate; as a side benefit, raising water levels would halt the decomposition of peat. Other areas of the polder would be left at lower grades and could absorb floods. A decision on what to do in the southwest polder is expected in the next two years. Visions for other parts of the country include floating towns, floatable roadways that could be used for evacuation, and tanks beneath buildings that could hold floodwater. All of this would be a big departure from the traditional Dutch development method: throw a couple of meters of sand on top of the ubiquitous peat, install pilings, and pour the concrete. Still, impressive though it sounds, erecting floating or floatable structures is the easy part. The hard part of adapting to climate change is the planning, which requires intensive forecasting, sophisticated modeling, and risk mitigation strategies.

The Dutch approach is gaining adherents around the world. "They are taking a systems approach that includes smart development," says Lewis E. Link, a former director of research and development at the U.S. Army Corps of Engineers and now a professor at the University of Maryland, who led a postmortem federal investigation of Louisiana's levee, pumping, and drainage systems after Hurricane Katrina. That means not just restricting building in certain areas but being smart about *how* to build in others. "I think in the U.S., we have been far too prone to let people build in vulnerable areas that then have to be protected," he says. "It is just a mad cycle. We have trapped ourselves into this, over and over and over again." Part of the problem in the United States, Link notes, is that the federal government has little control over land use, and local governments are often unwilling to challenge developers in areas that may face higher threat levels. In the Netherlands, the federal government can take more control, says Balfoort. "Sometimes you must make a top-down decision for the benefit of the nation as a whole," he observes. "You do not discuss Christmas with the turkey."

While it's not clear whether the United States' federal government will try to start making top-down decisions about land use in threatened areas, at least Dutch-American research cross-pollination is well under way. Link has just completed an assessment of the New Orleans area—similar to the one Mynett is performing at the Delft University of Technology—to gauge the current risks posed to the Gulf Coast by various storm scenarios. Mynett sits on a U.S. panel making a similar assessment of the Sacramento and San Joaquin River valleys in California.

All parties are watching to see how the Dutch fare with climate-resilient housing. Given the dangers faced by coastal areas and river deltas around the globe, the rest of the world may soon beat a path to the Netherlands, clamoring for technical expertise. But before anyone will come, the Dutch must build it. TR

David Talbot is Technology Review*'s chief correspondent.*

COURTESY OF DURA VERMEER

Our Microbial Menagerie

New genomic technologies allow us to study the thriving but mysterious populations of microörganisms in our bodies, providing important insights into obesity and other health problems.

By Emily Singer

Photographs by David Torrence

Anyone who's ever visited a research lab that studies mice knows how the animals stink. But the mice housed in rows of large plastic bubbles in Jeffrey Gordon's lab at the Washington University School of Medicine smell surprisingly pleasant. They've spent their entire lives in a sterile, protected environment, inhaling purified air. Because of their meticulous upbringing, they harbor none of the microbes that normally give mice their distinctive acrid odor.

But living free of the bacteria that colonize most animals has also had a profound effect on the mice's development. They have less fat than their microbe-ridden counterparts and have to eat 30 percent more food to maintain their weight. Their hearts are 20 percent smaller, and they have immature immune systems.

For the last decade, Gordon, a microbiologist and director of Washington University's Center for Genome Sciences, has been trying to figure out precisely why. He and his students have spent that time investigating the complex microbial world inside both mice and humans, attempting to determine how bacteria exert their broad influence on our health. Each of us contains roughly 10 times as many microbial cells as human ones. And while some microbes make us sick, many play vital roles in our physiology. They give us the ability to digest foods whose nutrients would otherwise be lost to us, and they make essential vitamins and amino acids our bodies can't.

And yet, because the vast majority of these microbes die when extracted from their native habitat, they have been impossible to study and have remained a mystery. "This is completely unexplored territory that is likely to have a large impact on our understanding of human health and disease," says George Weinstock, codirector of the Human Genome Sequencing Center at the Baylor College of Medicine in Houston.

Researchers in the emerging field of metagenomics are beginning to map that unexplored territory. New ultrafast DNA-sequencing technologies allow scientists to study the genetic makeup of entire microbial communities, each of which may contain hundreds or thousands of different species. For the first time, microbiologists can compare genetic snapshots of all the microbes inhabiting people who differ by age, origin, and health status. By analyzing the functions of those microbes' genes, they can figure out the main roles the organisms play in our bodies.

Ultimately, researchers hope to find out precisely how microörganisms lower or increase the risk of contracting certain diseases. Armed with that information, physicians might one day use an individual's microbial profile to diagnose a disease, or manipulate the organisms in our gut to treat or prevent health problems. "There are a whole host of properties that turn out to be dependent on the presence of healthy indigenous microbiota," says David Relman, a microbiologist at Stanford University. "As we recognize the fundamental importance of our microbial genome, it becomes increasingly important to understand the makeup of these communities and the roles they play."

Failed Diets Explained

Jeffrey Gordon is tall and lean and wears the academic's uniform of khakis and a button-down shirt. He doesn't seem the type to love the newspaper cartoon *Cathy*, whose main character has spent most of her comic life complaining about diets and bathing-suit shopping–but he has a framed print of a strip from last January on his office wall. The strip was inspired by a landmark paper Gordon pub-

GERM FREE Microbiologist Jeffrey Gordon reaches into a sterile cage to display one of his germ-free mice. The lack of normal microbes has adversely affected the mice's development.

lished in 2006, arguably the first major functional finding in human metagenomics. Dismissing various excuses for the failure of her diets, Cathy finally settles on what has to be the most bizarre excuse yet: "overly efficient intestinal microbes." Amazingly, it's scientifically justified.

In 2004, Gordon's team published a paper describing a genetic survey of the bacterial populations of fat and lean mice. Mice genetically engineered to be obese, Gordon found, harbored different populations of microbes than lean mice. Two major groups of bacteria, the Bacteroidetes and the Firmicutes, dominate both the human and the mouse gut; the obese mice had a lower percentage of Bacteroidetes and a higher percentage of Firmicutes. In 2006, the researchers published a follow-up study of 12 obese people showing that the same pattern held true in humans. The differences seemed to be related more to weight than to genetics; after losing weight for a year on either a low-carb or a low-fat diet, the obese subjects had gut-microbe profiles that more closely resembled their lean counterparts'.

In both studies, the researchers used a genetic surveying method known as DNA barcoding. First they created a genetic soup containing DNA fragments from all the microbial species found in a sample taken from one of their subjects—whether mouse or human. Then they sequenced a small segment of DNA that occurs in a slightly different version in every species. Analyzing these "bar codes" allows researchers to gauge the number of different types of bacteria in a sample, even if some of those bacteria have never been cultured or sequenced before.

The finding that the microbial populations of lean and obese people differ raised a tantalizing question: could gut bacteria affect a person's weight? To answer that question, Gordon and his collaborators needed more than just information on the different types of bacteria in the gut; they also needed to figure out whether the populations of gut microbes in obese and lean mice actually functioned differently.

The researchers attempted to sequence as much of the bacterial DNA from each mouse as they could. (Because this type of study analyzes DNA from hundreds to thousands of species, it is much more labor intensive than a traditional sequencing study, which analyzes fragments of DNA purified from a single species and then combines them like pieces in a linear jigsaw puzzle.) An analysis of the sequenced DNA revealed that the microbes from the obese mice had a higher percentage of genes involved in breaking down otherwise indigestible complex plant sugars that are common in the human diet. That means that animals harboring these microbes can more effectively squeeze the calories out of food. Cathy the beleaguered cartoon heroine was right: even if obese people eat the same amount of food as skinny people, they may be destined to gain more weight.

BUBBLE MICE **Raised under sterile conditions, mice must eat more to maintain weight, pointing to microbes' role in metabolism.**

What's more, this trait appears to be transferable. When germ-free mice had microbes from obese mice transplanted into their guts, they gained more fat than those with microbes from lean animals. "We don't know what chemical signals mandate this change [in the microbial population]," says Gordon. "But we do know there is a dynamic relationship between the amount of fat you have and these bugs."

Gordon hopes to eventually answer much broader questions about humans' microbial inhabitants. How does the makeup of these communities contribute to a person's health? What is the origin of each person's distinctive microbial menagerie? Are a person's microbes determined mostly by her diet, or by where she lives, or by some other aspect of her lifestyle? How do our microbial populations change over time? And perhaps most important, can we tinker with an individual's microbial profile to improve his or her health? Ultimately, says Gordon, "we'll get a much more transcendent view of ourselves as a supraorganism, with traits encoded by our human genes and by those in the genomes of our microbial partners."

Sequencing Microbial Complexity

One floor below Gordon's lab is Washington University's Genome Sequencing Center, one of the primary sites of the Human Genome Project. The center houses more than 130 "traditional" sequencing machines, capable of reading five to six billion letters of DNA every month. During a recent tour of the facility, Gordon whizzed past these genomic workhorses and down a hall to the room that houses the

center's newest acquisitions: two sequencing machines made by 454 Life Sciences of Branford, CT. The machines are among the world's fastest gene sequencers, each reading an impressive 100 million DNA letters during a seven-hour run *(see "Sequencing in a Flash," May/June 2007)*.

The 454 sequencers are at the heart of Gordon's next project. Researchers hope to learn how to manipulate the way microbes affect energy storage and metabolism—to predict and perhaps reduce the risk of obesity, or to aid people who are undernourished. To understand these effects, Gordon plans to compare the microbial profiles of family members—obese and lean siblings and their mothers—in unprecedented depth. That's possible thanks to the new machines, which can sequence hundreds of thousands of pieces of DNA in a single experiment; older machines can handle just a few hundred. Only after researchers have generated microbial profiles of many different people will they be able to gauge the normal variability of microbial profiles in people of different ages and origins. That, in turn, will help them determine which specific microbial changes can be linked to illnesses or other health issues.

A comprehensive effort to catalogue human microbial populations is far too large for a single lab to undertake. The National Institutes of Health acknowledged that in May by designating the human microbiome a "Roadmap initiative." That means that significant funding will be available to support research in this area over the next five years. Scientists hope the initiative will ultimately blossom into a microbial version of the Human Genome Project. The project will be challenging. "Even though a microbial genome is one-thousandth the size of the human genome," says Baylor's Weinstock, "the total number of microbial genes in [the human] body is much greater than [the number of] human genes, because you have so many different species."

The success of the project will depend not just on ever-faster sequencing technologies but on new techniques for analyzing all that data. Scientists can examine a metagenomic sequence in two ways: by studying microbial species separately and by studying the community of different species as a whole. The first approach involves piecing together individual genomes to deduce the roles that different species play in the gut. Most genomic-analysis tools, however, have trouble with the genetic soup that constitutes a metagenomic DNA sample. The second approach is to look at the genes from an entire microbial community at once, without trying to analyze how they fit together into genomes. This approach gives a better picture of how bacterial communities may have evolved to function as a group, but it has its own limitations. Metagenomic studies of the ocean and other ecosystems have already revealed an unexpected bounty of genetic diversity; many of the genes uncovered are entirely novel and their functions entirely unknown. So scientists will also need better ways to predict these genes' functions.

Taking Microbial Medicine

In an abandoned bubble cage in the room housing Gordon's sterile mice sits a carton of yogurt. Yogurt is full of living bacteria that are meant to be good for you, and Gordon is testing "probiotic" theories about the beneficial use of microörganisms. Technicians feed yogurt to both sterile mice and those that have been purposely infected with one or a few species of bacteria, whose effects on their health and microbial profiles the researchers are trying to gauge.

"Maybe microbes themselves, or microbe-derived chemicals, could become part of our 21st-century medicine cabinet," suggests Gordon. He envisions a day when a routine doctor's visit would include an analysis of our microbial inhabitants. "When we eat, should we consider caloric and nutritional value of food as absolute, or should we consider it based on an individual's microbial community?" he asks. Microbial profiles could also be used in diagnosing, and perhaps even treating, specific diseases.

Metagenomic studies could shed light on public-health issues, too. Microbiologists hypothesize that changes in the way we live—cleaner drinking water and growing use of antibiotics, for example—have changed which microbes colonize our bodies. This in turn may explain, at least in part, why many developed countries are seeing an abrupt rise in certain diseases, such as asthma, which is characterized by an excessive immune response in the lungs. In the absence of some types of bacteria, the immune system may develop or function abnormally. Martin Blaser, a microbiologist at New York University, says that almost everyone used to be infected with the gut microbe *H. pylori*, which has been linked to ulcers. Now only 10 percent of children in the United States carry the bacterium. Preliminary studies conducted by Blaser link its absence to asthma.

While scientists have been able to connect some disorders, such as ulcers, to the presence or absence of individual bacterial species, they have been unable to identify a single microbial culprit for many others. It's possible that changes in many microbial populations must occur together to boost the risk of contracting a particular disease. "Maybe it's the structure of the community that plays a role," Gordon says.

Back in the bubble cages, mice are eating, sleeping, and nursing their young. By showing how microbial populations affect their animal hosts, the studies taking place in the mice's sterile quarters could eventually have profound consequences for human health. But for now, they represent the first tentative, tantalizing forays into a mysterious microscopic world. TR

Emily Singer is the biotechnology and life sciences editor of Technology Review.

Essay

Artificial Intelligence Is Lost in the Woods

Our way out is to see that thinking is not the same as problem solving—and that machines will probably never be conscious.

By David Gelernter

Illustration by Eric Joyner

Artificial intelligence has been obsessed with several questions from the start: Can we build a mind out of software? If not, why not? If so, what kind of mind are we talking about? A conscious mind? Or an unconscious intelligence that seems to think but experiences nothing and has no inner mental life? These questions are central to our view of computers and how far they can go, of computation and its ultimate meaning—and of the mind and how it works.

They are deep questions with practical implications. AI researchers have long maintained that the mind provides good guidance as we approach subtle, tricky, or deep computing problems. Software today can cope with only a smattering of the information-processing problems that our minds handle routinely—when we recognize faces or pick elements out of large groups based on visual cues, use common sense, understand the nuances of natural language, or recognize what makes a musical cadence final or a joke funny or one movie better than another. AI offers to figure out how thought works and to make that knowledge available to software designers.

It even offers to deepen our understanding of the mind itself. Questions about software and the mind are central to cognitive science and philosophy. Few problems are more far-reaching or have more implications for our fundamental view of ourselves.

The current debate centers on what I'll call a "simulated conscious mind" versus a "simulated unconscious intelligence." We hope to learn whether computers make it possible to achieve one, both, or neither.

I believe it is hugely unlikely, though not impossible, that a conscious mind will ever be built out of software. Even if it could be, the result (I will argue) would be fairly useless in itself. But an *unconscious* simulated intelligence certainly could be built out of software—and might be useful. Unfortunately, AI, cognitive science, and philosophy of mind are nowhere near knowing how to build one. They are missing *the* most important fact about thought: the "cognitive continuum" that connects the seemingly unconnected puzzle pieces of thinking (for example analytical thought, common sense, analogical thought, free association, creativity, hallucination). The cognitive continuum explains how all these reflect different values of one quantity or parameter that I will call "mental focus" or "concentration"—which changes over the course of a day and a lifetime.

Without this cognitive continuum, AI has no comprehensive view of thought: it tends to ignore some thought modes (such as free association and dreaming), is uncertain how to integrate emotion and thought, and has made strikingly little progress in understanding analogies—which seem to underlie creativity.

My case for the near-impossibility of conscious software minds resembles what others have said. But these are minority views. Most AI researchers and philosophers believe that conscious software minds are just around the corner. To use the standard term, most are "cognitivists." Only a few are "anticognitivists." I am one. In fact, I believe that the cognitivists are even wronger than their opponents usually say.

But my goal is not to suggest that AI is a failure. It has merely developed a temporary blind spot. My fellow anticognitivists have knocked down cognitiv-

ism but have done little to replace it with new ideas. They've showed us what we can't achieve (conscious software intelligence) but not how we *can* create something less dramatic but nonetheless highly valuable: *unconscious* software intelligence. Once AI has refocused its efforts on the mechanisms (or algorithms) of thought, it is bound to move forward again.

Until then, AI is lost in the woods.

What Is Consciousness?

In conscious thinking, you experience your thoughts. Often they are accompanied by emotions or by imagined or remembered images or other sensations. A machine with a conscious (simulated) mind can feel wonderful on the first fine day of spring and grow depressed as winter sets in. A machine that is capable only of unconscious intelligence "reads" its thoughts as if they were on cue cards. One card might say, "There's a beautiful rose in front of you; it smells sweet." If someone then asks this machine, "Seen any good roses lately?" it can answer, "Yes, there's a fine specimen right in front of me." But it has no sensation of beauty or color or fragrance. It has no experiences to back up the currency of its words. It has no inner mental life and therefore no "I," no sense of self.

But if an artificial mind can perform *intellectually* just like a human, does consciousness matter? Is there any practical, perceptible advantage to simulating a conscious mind?

Yes.

An unconscious entity feels nothing, by definition. Suppose we ask such an entity some questions, and its software returns correct answers.

"Ever felt friendship?" The machine says, "No."

"Love?" "No." "Hatred?" "No." "Bliss?" "No."

"Ever felt hungry or thirsty?" "Itchy, sweaty, tickled, excited, conscience stricken?"

"Ever mourned?" "Ever rejoiced?"

No, no, no, no.

In theory, a *conscious* software mind might answer "yes" to all these questions; it would be conscious in the same sense you are (although its access to experience might be very different, and strictly limited).

So what's the difference between a conscious and an unconscious software intelligence? The potential *human presence* that *might* exist in the simulated conscious mind but could never exist in the unconscious one.

You could never communicate with an unconscious intelligence as you do with a human—or trust or rely on it. You would have no grounds for treating it as a being toward which you have moral duties rather than as a tool to be used as you like.

But would a simulated human presence have practical value? Try asking lonely people—and all the young, old, sick, hurt, and unhappy people who get far less attention than they need. A made-to-order human presence, even though artificial, might be a godsend.

AI (I believe) won't ever produce one. But it can still lead the way to great advances in computing. An *unconscious* intelligence might be powerful. Alan Turing, the great English mathematician who founded AI, seemed to believe (sometimes) that consciousness was *not* central to thought, simulated or otherwise.

He discussed consciousness in the celebrated 1950 paper in which he proposed what is now called the "Turing test." The test is meant to determine whether a computer is "intelligent," or "can think"—terms Turing used interchangeably. If a human "interrogator" types questions, on any topic whatever, that are sent to a computer in a back room, and the computer sends back answers that are indistinguishable from a human being's, then we have achieved AI, and our computer is "intelligent": it "can think."

Does artificial intelligence require (or imply the existence of) artificial consciousness? Turing was cagey on these questions. But he did write,

> I do not wish to give the impression that I think there is no mystery about consciousness. There is, for instance, something of a paradox connected with any attempt to localise it. But I do not think these mysteries necessarily need to be solved before we can answer the question with which we are concerned in this paper.

That is, can we build intelligent (or thinking) computers, and how can we tell if we have succeeded? Turing seemed to assert that we can leave consciousness aside for the moment while we attack simulated thought.

But AI has grown more ambitious since then. Today, a substantial number of researchers believe one day we will build conscious software minds. This group includes such prominent thinkers as the inventor and computer scientist Ray Kurzweil. In the fall of 2006, Kurzweil and I argued the point at MIT, in a debate sponsored by the John Templeton Foundation. This piece builds, in part, on the case I made there.

A Digital Mind

The goal of cognitivist thinkers is to build an artificial mind out of *software* running on a *digital computer*.

Why does AI focus on digital computers exclusively, ignoring other technologies? For one reason, because computers seemed from the first like "artificial brains," and the first AI programs of the 1950s—the "Logic Theorist," the "Geometry Theorem-Proving

Machine"—seemed at their best to be thinking. Also, computers are the characteristic technology of the age. It is only natural to ask how far we can push them.

Then there's a more fundamental reason why AI cares specifically about digital computers: *computation* underlies today's most widely accepted view of mind. (The leading technology of the day is often pressed into service as a source of ideas.)

The ideas of the philosopher Jerry Fodor make him neither strictly cognitivist nor anticognitivist. In *The Mind Doesn't Work That Way* (2000), he discusses what he calls the "New Synthesis"—a broadly accepted view of the mind that places AI and cognitivism against a biological and Darwinian backdrop. "The key idea of New Synthesis psychology," writes Fodor, "is that cognitive processes are *computational.* … A computation, according to this understanding, is a formal operation on syntactically structured representations." That is, thought processes depend on the *form*, not the meaning, of the items they work on.

In other words, the mind is like a factory machine in a 1940s cartoon, which might grab a metal plate and drill two holes in it, flip it over and drill three more, flip it sideways and glue on a label, spin it around five times, and shoot it onto a stack. The machine doesn't "know" what it's doing. Neither does the mind.

Likewise computers. A computer can add numbers but has no idea what "add" means, what a "number" is, or what "arithmetic" is for. Its actions are based on shapes, not meanings. According to the New Synthesis, writes Fodor, "the mind is a computer."

But if so, then a computer can be a mind, can be a *conscious* mind—*if* we supply the right software. Here's where the trouble starts. Consciousness is necessarily subjective: you alone are aware of the sights, sounds, feels, smells, and tastes that flash past "inside your head." This subjectivity of mind has an important consequence: *there is no objective way to tell whether some entity is conscious.* We can only guess, not test.

Granted, we know our fellow humans are conscious; but *how*? Not by testing them! You know the person next to you is conscious because *he is human.* You're human, and you're conscious—which moreover seems fundamental to your humanness. Since your neighbor is also human, he must be conscious too.

So how will we know whether a computer running fancy AI software is conscious? Only by trying to imagine *what it's like* to be that computer; we must try to see inside its head.

Which is clearly impossible. For one thing, it doesn't have a head. But a thought experiment may give us a useful way to address the problem. The "Chinese Room" argument, proposed in 1980 by John Searle, a philosophy professor at the University of California, Berkeley, is intended to show that no computer running software could possibly manifest understanding or be conscious. It has been controversial since it first appeared. I believe that Searle's argument is absolutely right—though more elaborate and oblique than necessary.

Searle asks us to imagine a program that can pass a Chinese Turing test—and is accordingly fluent in Chinese. Now, someone who knows English but no Chinese, such as Searle himself, is shut up in a room. He takes the Chinese-understanding software with him; he can execute it by hand, if he likes.

Imagine "conversing" with this room by sliding questions under the door; the room returns written answers. It *seems* equally fluent in English and Chinese. But actually, there is no understanding of Chinese inside the room. Searle handles English questions by relying on his knowledge of English, but to deal with Chinese, he executes an elaborate set of simple instructions mechanically. We conclude that to *behave* as if you understand Chinese doesn't mean you do.

But we don't need complex thought experiments to conclude that a conscious computer is ridiculously unlikely. We just need to tackle this question: *What is it like to be a computer running a complex AI program?*

Well, what does a computer do? It executes "machine instructions"—low-level operations like arithmetic (add two numbers), comparisons (which number is larger?), "branches" (if an addition yields zero, continue at instruction 200), data movement (transfer a number from one place to another in memory), and so on. Everything computers accomplish is built out of these primitive instructions.

So *what is it like to be a computer running a complex AI program?* Exactly like being a computer running *any other kind* of program.

Computers don't know or care what instructions they are executing. They deal with outward forms, not meanings. Switching applications changes the output, but those changes have meaning only to humans. *Consciousness*, however, doesn't depend on how anyone else interprets your actions; it depends on what *you yourself* are aware of. And the computer is merely a machine doing what it's supposed to do—like a clock ticking, an electric motor spinning, an oven baking. The oven doesn't care what it's baking, or the computer what it's computing.

The computer's routine never varies: grab an instruction from memory and execute it; repeat until something makes you stop.

Of course, we can't know *literally* what it's like to be a computer executing a long sequence of instructions. But we know what it's like to be a human doing the same. Imagine holding a deck of cards. You sort the deck; then you shuffle it and sort it again. Repeat the procedure, ad infinitum. You are doing comparisons (which card comes first?), data movement (slip one card in front of another), and so on. To know what it's like to be a computer running a sophisticated AI application, sit down and sort cards all afternoon. That's what it's like.

If you sort cards long enough and fast enough, will a brand-new conscious mind (somehow) be created? This is, in effect, what cognitivists believe. They say that when a computer executes the right combination of primitive instructions in the right way, a new conscious mind will emerge. So when a *person* executes the right combination of primitive instructions in the right way, a new conscious mind should (also) emerge; there's no operation a computer can do that a person can't.

Of course, humans *are* radically slower than computers. Cognitivists argue that *sure*, you know what executing low-level instructions *slowly* is like; but only when you do them *very fast* is it possible to create a new conscious mind. Sometimes, a radical change in execution speed *does* change the qualitative outcome. (When you look at a movie frame by frame, no illusion of motion results. View the frames in rapid succession, and the outcome is different.) Yet it seems arbitrary to the point of absurdity to insist that doing many primitive operations *very fast* could produce consciousness. Why should it? Why would it? How could it? What makes such a prediction even remotely plausible?

But even if researchers could make a conscious mind out of software, it wouldn't do them much good.

Suppose you *could* build a conscious software mind. Some cognitivists believe that such a mind, all by itself, is AI's goal. Indeed, this is the message of the Turing test. A computer can pass Turing's test without ever mingling with human beings.

But such a mind could communicate with human beings only in a drastically superficial way.

It would be capable of feeling emotion in principle. But *we* feel emotions with our whole bodies, not just our minds; and *it* has no body. (Of course, we could say, then build it a humanlike body! But that is a large assignment and poses bioengineering problems far beyond and outside AI. Or we could build our new mind a body unlike a human one. But in that case we couldn't expect its emotions to be like ours, or to establish a common ground for communication.)

Consider the low-energy listlessness that accompanies melancholy, the overflowing jump-for-joy sensation that goes with elation, the pounding heart associated with anxiety or fear, the relaxed calm when we are happy, the obvious physical manifestations of excitement—and other examples, from rage to panic to pity to hunger, thirst, tiredness, and other conditions that are equally emotions and bodily states. In all these cases, your mind and body form an integrated whole. No mind that lacked a body like yours could experience these emotions the way you do.

No such mind could even grasp the word "itch."

In fact, even if we achieved the bioengineering marvel of a synthetic human body, our problems wouldn't be over. Unless this body experienced infancy, childhood, and adolescence, as humans do—unless it could grow up, as a member of human society—how could it understand what it means to "feel like a kid in a candy shop" or to "wish I were 16 again"? How could it grasp the human condition in its most basic sense?

A mind-in-a-box, with no body of any sort, could triumphantly pass the Turing test—which is one index of the test's superficiality. Communication with such a contrivance would be more like a parody of conversation than the real thing. (Even in random Internet chatter, all parties know what it's like to itch, and scratch, and eat, and be a child.) Imagine talking to someone who happens to be as articulate as an adult but has less experience than a six-week-old infant. Such a "conscious mind" has no advantage, in itself, over a mere unconscious intelligence.

But there's a solution to these problems. Suppose we set aside the gigantic chore of building a synthetic human body and make do with a mind-in-a-box or a mind-in-an-anthropoid-robot, equipped with video cameras and other sensors—a rough approximation of a human body. Now we choose some person (say, Joe, age 35) and simply copy all his memories and transfer them into our software mind. Problem solved. (Of course, we don't know how to do this; not only do we need a complete transcription of Joe's memories, we need to translate them from the neural form they take in Joe's brain to the software form that our software mind understands. These are hard, unsolved problems. But no doubt we will solve them someday.)

Nonetheless: understand the enormous ethical burden we have now assumed. Our software mind is *conscious* (by assumption) just as a human being is; it can feel pleasure and pain, happiness and sadness, ecstasy and misery. Once we've transferred Joe's memories into this artificial yet conscious being, it can remember *what it was like* to have a human body—to feel spring rain, stroke someone's face, drink when it was thirsty, rest when its muscles were tired, and so forth. (Bodies

are good for many purposes.) But our software mind has *lost* its body—or had it replaced by an elaborate prosthesis. What experience could be more shattering? What loss could be harder to bear? (Some losses, granted, but not many.) What gives us the right to inflict such cruel mental pain on a conscious being?

In fact, what gives us the right to create such a being and treat it like a tool to begin with? Wherever you stand on the religious or ethical spectrum, you had better be prepared to tread carefully once you have created consciousness in the laboratory.

The Cognitivists' Best Argument

But not so fast! say the cognitivists. Perhaps it seems arbitrary and absurd to assert that a conscious mind can be created if certain simple instructions are executed very fast; yet doesn't it *also* seem arbitrary and absurd to claim that you can produce a conscious mind by gathering together lots of neurons?

The cognitivist response to my simple thought experiment ("Imagine you're a computer") might run like this, to judge from a recent book by a leading cognitivist philosopher, Daniel C. Dennett. Your mind is conscious; yet it's built out of huge numbers of tiny *unconscious* elements. There are no raw materials for creating consciousness except *unconscious* ones.

Now, compare a neuron and a yeast cell. "A hundred kilos of yeast does not wonder about Braque," writes Dennett, "… but you do, and you are made of parts that are fundamentally the same sort of thing as those yeast cells, only with different tasks to perform." Many neurons add up to a brain, but many yeast cells don't, because neurons and yeast cells *have different tasks to perform*. They are programmed differently.

In short: if we gather huge numbers of unconscious elements together in the right way and give them the right tasks to perform, then at some point, *something happens*, and consciousness emerges. That's how your brain works. Note that neurons work as the raw material, but yeast cells don't, because neurons *have the right tasks to perform*. So why can't we do the same thing using software elements as raw materials—so long as we give them the right tasks to perform? Why shouldn't *something happen*, and yield a conscious mind built out of software?

Here is the problem. Neurons and yeast cells don't merely have "different tasks to perform." They perform differently because they are *chemically* different.

One water molecule isn't wet; two aren't; three aren't; 100 aren't; but at some point we cross a threshold, *something happens*, and the result is a drop of water. *But this trick only works because of the chemistry and physics of water molecules!* It won't work with just *any* kind of molecule. Nor can you take just any kind of molecule, give it the right "tasks to perform," and make it a fit raw material for producing water.

The fact is that the conscious mind emerges when we've collected many *neurons* together, not many doughnuts or low-level computer instructions. Why should the trick work when I substitute simple computer instructions for neurons? Of course, it *might* work. But there isn't any reason to believe it *would*.

My fellow anticognitivist John Searle made essentially this argument in a paper that referred to the "causal properties" of the brain. His opponents mocked it as reactionary stuff. They asserted that since Searle is unable to say just how these "causal properties" work, his argument is null and void. Which is nonsense again. I don't need to know anything at all about water molecules to realize that large groups of them yield water, whereas large groups of krypton atoms don't.

Why the Cognitive Spectrum Is More Exciting than Consciousness

To say that building a useful conscious mind is highly unlikely is not to say that AI has nothing worth doing. Consciousness has been a "mystery" (as Turing called it) for thousands of years, but the mind holds other mysteries, too. Creativity is one of the most important; it's a brick wall that psychology and philosophy have been banging their heads against for a long time. Why should two people who seem roughly equal in competence and intelligence differ dramatically in creativity? It's widely agreed that discovering new analogies is the root (or *one* root) of creativity. But how are new analogies discovered? We don't know. In his 1983 classic *The Modularity of Mind*, Jerry Fodor wrote, "It is striking that, while everybody thinks analogical reasoning is an important ingredient in all sorts of cognitive achievements that we prize, nobody knows anything about how it works."

Furthermore, to speak of the mystery of consciousness makes consciousness sound like an all-or-nothing proposition. But how do we explain the different kinds of consciousness we experience? "Ordinary" consciousness is different from your "drifting" state when you are about to fall asleep and you register external events only vaguely. Both are different from hallucination as induced by drugs, mental illness—or life. We hallucinate every day, when we fall asleep and dream.

And how do we explain the difference between a child's consciousness and an adult's? Or the differences between child-style and adult-style *think-*

ing? Dream thought is different from drifting or free-associating pre-sleep thought, which is different from "ordinary" thought. We know that children tend to think more concretely than adults. Studies have also suggested that children are better at inventing metaphors. And the keenest of all observers of human thought, the English Romantic poets, suggest that dreaming and waking consciousness are less sharply distinguished for children than for adults. Of his childhood, Wordsworth writes (in one of the most famous short poems in English), "There was a time when meadow, grove, and stream, / The earth, and every common sight, / To me did seem / Apparelled in celestial light, / The glory and the freshness of a dream."

Today's cognitive science and philosophy can't explain any of these mysteries.

The philosophy and science of mind has other striking blind spots, too. AI researchers have been working for years on common sense. Nonetheless, as Fodor writes in *The Mind Doesn't Work That Way*, "the failure of artificial intelligence to produce successful simulations of routine commonsense cognitive competences is notorious, not to say scandalous." But the scandal is wider than Fodor reports. AI has been working in recent years on emotion, too, but has yet to understand its integral role in thought.

In short, there are *many* mysteries to explain—and many "cognitive competences" to understand. AI—and software in general—can profit from progress on these problems even if it can't build a conscious computer.

These observations lead me to believe that the "cognitive continuum" (or, equally, the *consciousness* continuum) is the most important and exciting research topic in cognitive science and philosophy today.

What is the "cognitive continuum"? And why care about it? Before I address these questions, let me note that the cognitive continuum is not even a scientific theory. It is a "prescientific theory"—like "the earth is round."

Anyone might have surmised that the earth is round, on the basis of everyday observations—especially the way distant ships sink gradually below (or rise above) the horizon. No special tools or training were required. That the earth is round leaves many basic phenomena unexplained: the tides, the seasons, climate, and so on. But unless we know that the earth is round, it's hard to progress on any of these problems.

The cognitive continuum is the same kind of theory. I don't claim that it's a millionth as important as the earth's being round. But for me as a student of human thought, it's at least as exciting.

What is this "continuum"? It's a spectrum (the "cognitive spectrum") with infinitely many intermediate points between two endpoints.

When you think, the mind assembles thought trains—sequences of distinct thoughts or memories. (Sometimes one blends into the next, and sometimes our minds go blank. But usually we can describe the train that has just passed.) Sometimes our thought trains are assembled—so it seems—under our conscious, deliberate control. Other times our thoughts wander, and the trains seem to assemble themselves. If we start with these observations and add a few simple facts about "cognitive behavior," a comprehensive picture of thought emerges almost by itself.

Obviously, you must be alert to think analytically. To solve a set of mathematical equations or follow a proof, you need to *focus your attention*. Your concentration declines as you grow tired over the day.

And your mind is in a strange state just before you fall asleep: a free-associative state in which, rather than following from another logically, one thought "suggests" the next. In this state, you *cannot* focus: if you decide to think about one thing, you soon find yourself thinking about something else (which was "suggested" by thing one), and then something else, and so on. In fact, cognitive psychologists have discovered that we start to dream *before* we fall asleep. So the mental state right before sleep is the state of dreaming.

Since we start the day in one state (focused) and finish in another (free-associating, unfocused), the two must be connected. Over the day, focus declines—perhaps steadily, perhaps in a series of oscillations.

Which suggests that there is a *continuum* of mental states between highest focus and lowest. Your "focus level" is a large factor in determining your mode of thought (or of consciousness) at any moment. This spectrum must stretch from highest-focus thought (best for reasoning or analysis) downward into modes based more on experience or common sense than on abstract reasoning; down further to the relaxed, drifting thought that might accompany gazing out a window; down further to the uncontrolled free association that leads to dreaming and sleep—where the spectrum bottoms out.

Low focus means that your *tendency* (not necessarily your ability) to free-associate increases. A wide-awake person can free-associate if he tries; an exhausted person has to try hard *not* to free-associate. At the high end, you concentrate unless you try not to. At the low end, you free-associate unless you try not to.

Notice that the role of associative recollection—in which one thought or memory causes you to recall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another—increases as you move down-spectrum. Reasoning works (theoretically) from first principles. But common sense depends on your recalling a familiar idea or technique, or a previous experience. When your mind drifts as you look out a window, one recollection leads to another, and to a third, and onward—but eventually you return to the task at hand. Once you reach the edge of sleep, though, free association goes unchecked. And when you dream, one character or scene transforms itself into another smoothly and illogically—just as one memory transforms itself into another in free association. Dreaming is free association "from the inside."

At the high-focus end, you assemble your thought train as if you were assembling a comic strip or a storyboard. You can step back and "see" many thoughts at once. (To think analytically, you must have your premises, goal, and subgoals in mind.) At the high-focus end, you manipulate your thoughts as if they were objects; you *control* the train.

At the bottom, it's just the opposite. You don't control your thoughts. You say, "my mind is wandering," as if you and your mind were separate, as if your thoughts were roaming around by themselves.

If at high focus you manipulate your thoughts "from the outside," at low focus you step *into* each thought as if you were entering a room; you inhabit it. That's what hallucination means. The opposite of high focus, where you control your thoughts, is hallucination—where your thoughts control you. *They* control your perceived environment and experiences; you "inhabit" each in turn. (We sometimes speak of "surrendering" to sleep; surrendering to your thoughts is the opposite of controlling them.)

At the high-focus end, your "I" is separate from your thought train, observing it critically and controlling it. At the low end, your "I" blends into it (or climbs aboard).

The cognitive continuum is, arguably, the single most important fact about thought. If we accept its existence, we can explain and can *model* (say, in software) the dynamics of thought. Thought styles change throughout the day as our focus level changes. (Focus levels depend, in turn, partly on personality and intelligence: some people are capable of higher focus; some are more *comfortable* in higher-focus states.)

It also seems logical to surmise that cognitive maturing increases the focus level you are able to reach and sustain—and therefore increases your ability *and* tendency to think abstractly.

Even more important: if we accept the existence of the spectrum, an explanation and model of *analogy discovery*—thus, of creativity—falls into our laps.

As you move down-spectrum, where you *inhabit* (not observe) your thoughts, you *feel* them. In other words, as you move down-spectrum, *emotions* emerge. Dreaming, at the bottom, is emotional.

Emotions are a powerful coding or compression device. A bar code can encapsulate or encode much information. An emotion is a "mental bar code" that encapsulates a memory. But the function $E(m)$—the "emotion" function that takes a memory m and yields the emotion *you in particular* feel when you think about m—does not generate unique values. Two different-seeming memories can produce the same emotion.

How do we invent analogies? What made Shakespeare write, "Shall I compare thee to a summer's day?" Shakespeare's lady didn't *look* like a summer's day. (And what does a "summer's day" look like?)

An analogy is a two-element thought train—"a summer's day" followed by the memory of some person. Why should the mind conjure up these two elements in succession? What *links* them?

Answer: in some cases (perhaps in many), their "emotional bar codes" match—or were sufficiently similar that one recalled the other. The lady and the summer's day made the poet *feel* the same sort of way.

We experience more emotions than we can name. "Mildly happy," "happy," "ebullient," "elated"; our choice of English words is narrow. But how do you feel when you are about to open your mailbox, expecting a letter that will probably bring good news but *might* be crushing? When you see a rhinoceros? These emotions have no names. But each "represents" or "encodes" some collection of circumstances. Two experiences that *seem* to have nothing in common might awaken—*in you only*—the same emotion. And you might see, accordingly, an analogy that no one else ever saw.

The cognitive spectrum suggests that analogies are created by *shared emotion*—the linking of two thoughts with shared or similar emotional content.

To build a simulated unconscious mind, we don't need a computer with real emotions; simulated emotions will do. Achieving them will be hard. So will representing memories (with all their complex "multimedia" data).

But if we take the route Turing hinted at back in 1950, if we forget about consciousness and concentrate on the *process of thought*, there's every reason to believe that we can get AI back on track—and that AI can produce powerful software *and* show us important things about the human mind. TR

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SECURITY

Iris Scanning, Now at JFK

Registered-traveler programs offer a quicker and more convenient journey, at a cost in privacy. **By Bryant Urstadt**

In May, I gave up my fingerprints and a scan of my irises and joined a program called Clear at the British Airways terminal at John F. Kennedy International Airport in New York, thus becoming one of the first "registered travelers." The registered-traveler program is based on a set of standards, issued by the U.S. government, that's meant to speed "safe" passengers through airport security checks. Launched in 2005 and implemented by private contractors, it's designed to help airports improve efficiency by separating trusted travelers from the unknown. Clear opened the first dedicated registered-traveler lane at Orlando International Airport in 2005, and four more have followed. A whole nation's worth, of course, is planned.

Clear is operated by Verified Identity Pass, a startup company founded in 2003 by Steven Brill, a serial entrepreneur who also started the magazine *American Lawyer* and Court TV. Although Unisys and other companies are working on lanes of their own, Verified is the only company to have some in operation already. Access to the lanes is granted on a subscription basis, and membership in Clear's program costs $99.95 a year. More than 45,000 people have joined so far; equipped with an identity card featuring a chip full of biometric information, the Clear subscriber often passes through security in less than a minute.

Clear maintains a full-time registration center in the BA terminal. Prominently situated on the departure level, right by the main entrance, it is a slick little nugget of design, with illuminated sky-blue cubes floating over registration and verification terminals. When I visited, there were two attendants wearing sharp Clear uniforms, which featured navy skirts and blue scarves. I filled out an application on one of the company's laptop computers, providing many details about myself: Social Security number, driver's-license number, passport number, height.

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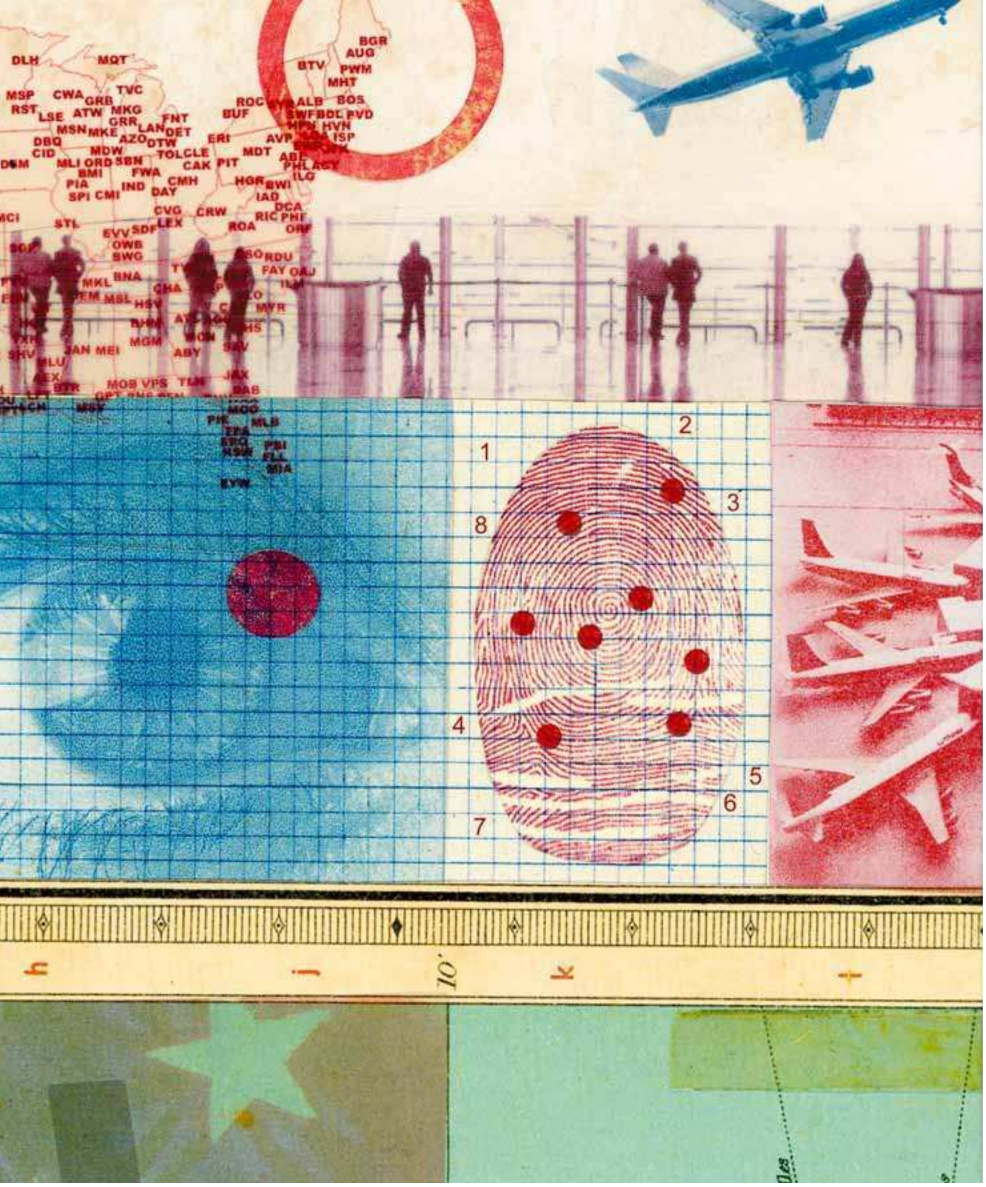
Then I stepped up to the verification kiosk, a machine cobbled together from off-the-shelf products, both common and specialized, including a touch-screen PC. The attendant typed in my account number, scanned my passport in a document scanner, and slid my driver's license into a card reader. Next, I slapped my palm down on a fingerprint scanner, which took a read of all my fingerprints. A smaller scanner then read several of my fingers individually, and the finger that gave the most consistent reading on both scans—my left ring finger—was selected as my passkey to Clear travel.

I turned my attention to the iris capture system, tipping a narrow one-way mirror until I could see my eyes in it and then following the computer's verbal instructions to step back or move closer until my eyes were at the right distance. I focused on an oval in the middle of the mirror and then relaxed my eyes until I was looking straight ahead. At that point, I saw not one but two ovals, each centered over an iris, and the camera snapped a picture of my irises. Finally, the machine took my picture with a webcam that looked just like the one I have sitting over my computer monitor at home.

I was almost a registered traveler. As I write, my information has been sent to the U.S. Transportation Security Administration (TSA), which will make a decision on my suitability for speedy travel by checking my information against a database of terrorists and investigating my criminal history. If I'm cleared, in two weeks to a month I will find in my mailbox a translucent card with a chip embedded in it, containing all that I relinquished.

Initially, the card will be valid only at five airports, but if all goes according to Clear's plan, it will one day whisk me through security gates not just at many other U.S. airports but at train stations, stadiums, office and government buildings, and anywhere else security might ever be an issue. It would be, at that scale, the private equivalent of a national identity card, and "optional" in the same way that a telephone number or a driver's license



MARTIN O'NEILL

is now optional. The Clear card is compliant with federal standards for the registered-traveler program, so it will work in the lanes of competing contractors, wherever they may be.

A Way to Keep Your Shoes On

Although the TSA does not mandate separate security technology for registered-traveler programs, Clear has developed its own checkpoint scanning system, which is more advanced than those found in airports' public lanes. It's likely to give the company a commercial foothold should it begin offering primary security services in venues other than airports. Parts of the system are already in use or pending approval at several locations; together, they should allow a given traveler to pass through security without having to remove her shoes or jacket or take her laptop out of its bag.

The centerpiece of the system is the SRT kiosk, a machine developed by GE Security that costs around $150,000. To use it, you take a few steps up onto a platform, insert your biometric card, and confirm your identity with a fingerprint or iris scan. Then, if the machine is approved in its current configuration, you'll be checked for explosives.

Shoes will be scanned for explosives using quadrupole resonance. This technique has been around for some time; it was used in Vietnam to look for land mines, and it is a cousin of magnetic resonance imaging. It uses radio waves to excite the molecules in the shoes. When the molecules calm down, they release the extra energy as radiation. Some frequencies of radiation indicate explosives; others indicate normal shoe materials. The system is currently approved for use in Orlando and is expected to be approved at the other airports soon.

Also pending approval from the TSA is a process in which the traveler will place a finger on a trace explosive detector, a pad designed as an alternative to the walk-through arches under which travelers stand while puffs of air dislodge any detectable traces of explosives adhering to their bodies or clothes. Though it may seem unlikely that a finger scan could replace the examination of a person's entire body, GE believes that the particles in explosives are "sticky" enough for a fingertip to provide an adequate sample. GE is also working on separate scanners using computed tomography, which will generate images of laptops left resting in their bags.

"Overall, Clear is not only going to be more convenient; it's going to provide a higher level of security," says Matthew Farr, a senior homeland security analyst with consultants Frost and Sullivan. "I think it's all going to fundamentally change airport security."

But every advance in security seems to demand a corresponding regression in privacy, and there are many who consider the idea of registering to travel an assault on liberty. What's more, they object to being asked to give up all 10 fingerprints, an intrusion that few people other than suspected criminals have had to endure. Though some passports are now issued with biometric-capable chips built in, the U.S. Department of Homeland Security's 2004 decision to fingerprint some foreign travelers as a matter of course sparked outrage in the U.S. and abroad. Bringing the policy closer to general implementation, even in a voluntary program, would raise even more ire. (The idea that a traveler's movements would be recorded may not be an issue, for Clear claims that its

travel records are not network accessible and are erased every 24 hours.)

Tim Sparapani, a legislative counsel at the American Civil Liberties Union who specializes in privacy, national security, and immigration, is particularly concerned about what happens if you don't make the list. He imagines a whole underclass of unregisterables—who if the program ever does expand to places like office buildings and subways will be impeded all the more.

By promoting the development of accurate and convenient screening technology, though, Clear's registered-traveler program may actually increase the efficiency of security checking for all travelers. Advanced detection, as it filters down to the general public, might simultaneously speed up lines and lessen the demand for privileged lanes and registration programs themselves. (That's an outcome that could trouble a long-term investor in Clear, but the company would lose its advantage only at the airline gate, not at any public or private venues it separately negotiated to screen. Those venues would be open to competition, in which Clear would have the advantage of having established itself as a leader in the business. And there are more office buildings and stadiums than airline gates.) Simply perfecting a machine, whose implementation does not require traveler registration, would deliver something close to a truly democratic screening method for travel.

So far, Clear has built a few things of importance, including a model for a trusted-traveler program, a useful registration center, and a security checkpoint that, though it's a work in progress, may one day benefit all travelers, whether they carry biometric cards or not. It's hard to cheer any program that includes a list kept by the government, but does this one herald the further and final deterioration of liberty? Not necessarily. TR

Bryant Urstadt has written for Harper's *and* Rolling Stone.

COMPUTER SCIENCE

Artificial Societies and Virtual Violence

How modeling societies *in silico* can help us understand human inequality, revolution, ethnic cleansing, and genocide.

By Mark Williams

Paul Krugman, the distinguished Princeton University economics professor and *New York Times* columnist, once explained the jejune motives for his choice of career. "In my early teens my secret fantasy was to become a psychohistorian," he wrote, referring to the central gimmick, "psychohistory," of Isaac Asimov's *Foundation* trilogy. Krugman continued, "Someday there will exist a unified social science of the kind that Asimov imagined, but for the time being economics is as close to psychohistory as you can get."

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By Joshua M. Epstein
Princeton Studies in Complexity series
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That's risible, given the gulf between Asimov's fantasy of a predictive calculus of human affairs and the actuality of mainstream economics—indeed, of any of the social sciences—as practiced during most of the last century. Recent decades, though, have seen new approaches. One of the most promising was described by Joshua Epstein, a senior fellow at the Brookings Institution, in *Growing Artificial Societies: Social Science from the Bottom Up*, a book he published in 1996 in collaboration with Robert Axtell. "Perhaps one day people will interpret the question, 'Can you explain it?' as asking 'Can you *grow* it?'" Epstein suggested. "Artificial society modeling allows us to 'grow' social structures *in silico* demonstrating that certain sets of microspecifications are *sufficient to generate* the macrophenomena of interest."

What does this mean? And why should we care? Epstein's claim was twofold. First, he pointed out that while almost all the patterns that interest social scientists are emergent ones—that is, complex developments arising from a lot of relatively simple interactions—disciplines such as mainstream economics conceive of societies as tending toward some notional equilibrium. Standard explanations assume, too, that societies consist of highly rational agents who, possessing full knowledge, act always in their own best interest. When it comes to how real populations of diverse actors with limited rationality actually evolve their patterns of, say, wealth distribution, Epstein noted, the stock explanations have almost nothing to say.

Epstein was hardly alone in making those criticisms. But he proposed, secondly, that computer models *in themselves* could effectively describe societies. In the early 1990s, Epstein and Axtell had created a simulation called Sugarscape, a square grid representing a two-dimensional landscape inhabited by autonomous subprograms—agents—that were driven from square to square by crude artificial metabolisms that demanded a resource, designated "sugar." When hundreds of these agents were programmed so that their ranges of vision and metabolic rates varied, even in simple ways, surprising patterns emerged.

Indeed, Epstein and Axtell would learn that with their models, "the trick [was] to get a lot *out*, while putting in as little as possible," as Epstein writes in his latest book, *Generative Social Science: Studies in Agent-Based Computational Modeling*. In the early 1990s,

the two men set up two regions of their Sugarscape grid to be rich in the sugar resource, so that agents quickly gravitated toward them. A few agents with superior vision and low metabolic rates accumulated large sugar stocks. Other agents, with weaker vision and high metabolic rates, subsisted or died in zones where sugar was in short supply. Essentially, Epstein and Axtell found, Sugarscape functioned as a model of a hunter-gatherer society, reproducing a common feature of human societies: skewed wealth distribution. Granted, the notion that crude automata moving around a computer grid suggest that wealth inequality is an innate feature of human existence will be disliked not only by Marxists but by most of the rest of us, given how varied we know our individual experiences to be. Nevertheless, nature is full of peculiarly consistent statistical relationships, which reoccur across dissimilar realms and which statisticians call "power laws."

The most common power law is the Pareto distribution, named for the 19th-century Italian economist Vilfredo Pareto. In the late 1890s, Pareto argued that in any given society, 20 percent of the people will hold 80 percent of the wealth. But the Pareto distribution, also known as the "80-20 rule," holds in such diverse human contexts as size of settlements (a few big cities, many smaller towns) and frequency of words in text (a few words used often, most words infrequently), as well as for natural phenomena like the size of sand particles and of meteorites. That the behavior of Sugarscape's automata yielded power law–type distributions indicated to Epstein and Axtell that they were on to something.

In the early 1990s, Epstein gave a presentation at the Santa Fe Institute in New Mexico, a center for the study of complex adaptive systems across natural, human, and artificial contexts. "I showed one of our artificial histories set in the standard Sugarscape landscape with two sugar peaks, a sugar lowland in the middle, and sugar badlands on the sides—effectively, a simple valley representation," Epstein told me. "I asked the audience if it reminded anybody of anything. George Gumerman's hand shot up, and he said, 'It reminds me of the Anasazi.'"

George Gumerman is an anthropologist who for decades has been a leading expert on the Anasazi, ancestors of the present-day Pueblo peoples who from roughly 1800 B.C.E. to 1300 C.E. inhabited Long House Valley in northeast Arizona. Epstein and Axtell decided to use their agent-based modeling to create a virtual Anasazi civilization and see how it matched up against the extensive database of settlement patterns and the like assembled by Gumerman and his colleagues. Epstein recalled, "We started over, building the artificial terrain from scratch, with great exactitude." Elements like climate patterns, maize yields, fluctuations of the water table, and multitudes of other factors went into the model. "The big trick was, Could we come up with good rules for our artificial Anasazi, put them where the real ones were in 900 A.D., and let them run till they grew the true history?" Epstein remembered one session in which his team's artificial Anasazi established a settlement exactly where Long House, the real Anasazi settlement, had been. "We just sat screaming into the air with gratification. The entire business has come an awfully long way since then. Now there's many people doing this kind of work."

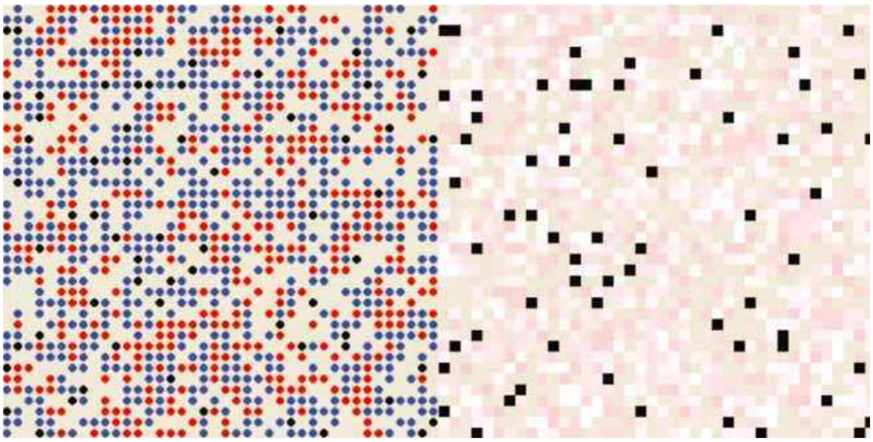


FIGURE 1: **Action and grievance screens**

Indeed. The website of the *Journal of Artificial Societies and Social Simulation*, for instance, lists papers with titles such as "Cascades of Failure and Extinction in Evolving Complex Systems." Epstein's new book collects his own papers since 1996; an accompanying CD lets readers watch runs of the models described in the text and explore the models on their own. In the projects described in the book, Epstein and his collaborators modeled, in addition to the Anasazi, the emergence of various phenomena: patterns in the timing of retirement; social classes; thoughtless conformity to social norms; patterns of smallpox infection after a bioterrorist incident; and successful, adaptive organization.

The models are fascinating. In both of the variants described in "Generating Patterns of Spontaneous Civil Violence" (see figures 1 and 2), there are regular agents as well as agents called cops, representing a central political authority. The left screen depicts regular agents' overt behavior (blue if quiescent, red if active) and the right the underlying "emotionscape," where agents are colored according to their level of political grievance (the darker the red, the higher the grievance).

Grievance has two components: legitimacy (L) of the state, as perceived by the agents, and hardship (H), which is physical or economic privation and varies between agents. Furthermore, agents can deceive: on the left screen, aggrieved agents can turn blue (appearing nonrebellious) when cops (always black) are near, then turn red (actively rebellious) when cops move away. Epstein also assigned varying levels of risk aversion (R) to the agents: some are more inclined to rebel than others. Agents assess their likelihood of arrest by cops before joining a rebellion, and their assessments depend on their vision (v) of what's around them—that is, how many grid positions (north, south, east, and west) they can see. Finally, agents arrested by cops receive jail sentences (J). "Arrested agents go to jail for a random duration and emerge as aggrieved as they went in," Epstein told me. "I always joke that those are the only two realistic assumptions in the whole model."

Though this model may seem overly simple, it generates realistic enough patterns once the human operator sets the parameters of L and J, the agents' and cops' vision, and their initial densities and then lets both groups move around and interact. In variant one, "Generalized Rebellion against Central Authority" (see figure 1), high concentrations of activist, aggrieved agents can arise in zones with low cop densities. When that happens, even mildly aggrieved agents find it rational to risk rebellion. It's for just this reason that freedom of assembly is generally the first thing curtailed under repressive regimes. Furthermore, the model displays the hallmark of a complex system: punctuated equilibrium, with long periods of relative stability broken by rebellious outbursts. In some runs, the right-hand "emotionscape" screen may be bright red with the agents' grievance, while the left screen is entirely blue because of their public quiescence. Which would be more likely to trigger revolution: a large absolute reduction of L (legitimacy) in small increments or a smaller reduction carried out in one large step? The latter, it turns out. In the case of the large but incremental reduction, cops can pick off activist agents one by one and jail them. Conversely, a sudden, sharp reduction in legitimacy spurs multiple aggrieved agents into active rebellion at once. As Epstein noted, "Once there are 50 people rebelling, it's a lot less risky to be the 51st."

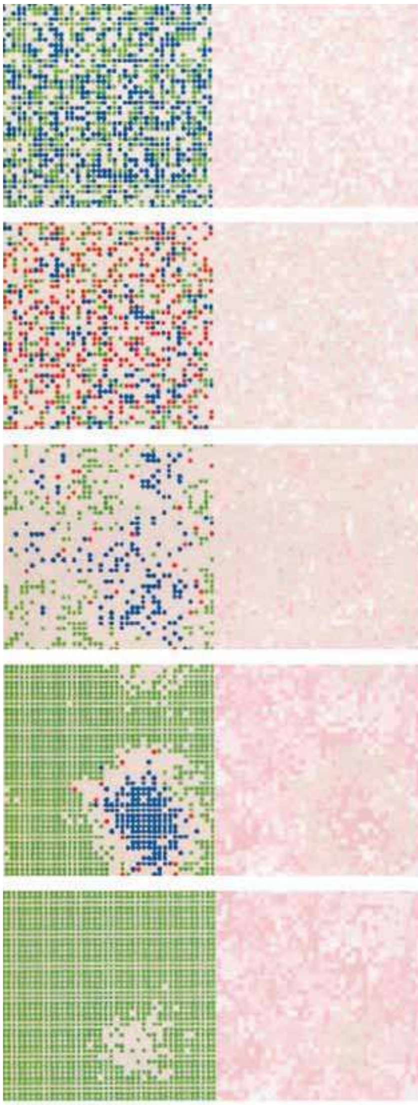
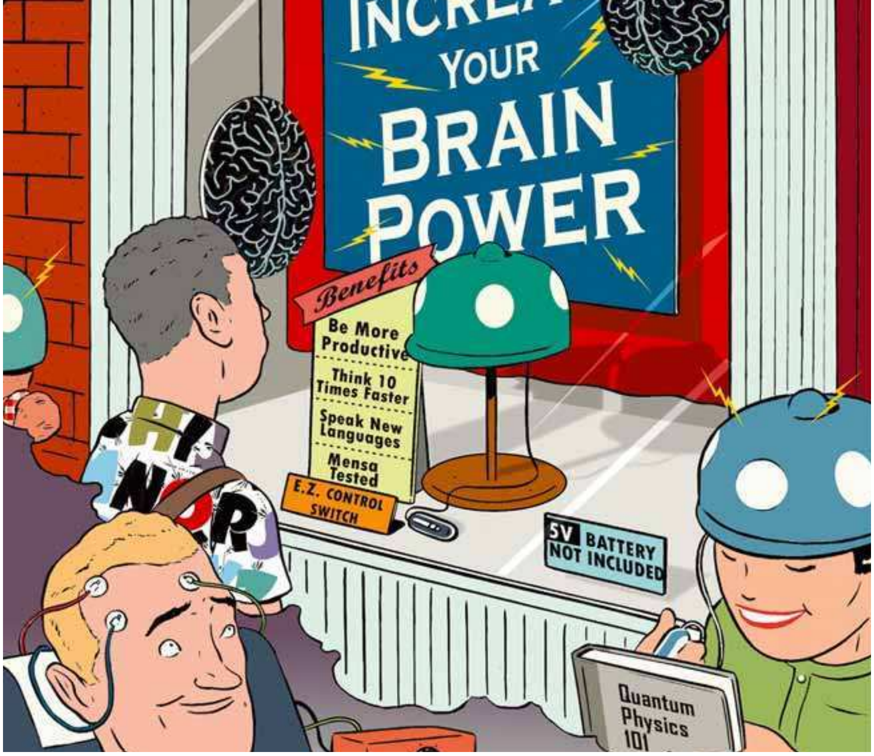


FIGURE 2: **Local ethnic cleansing to genocide**

Variant two, "Inter-Group Violence," is more interesting. Now agents are divided into two ethnicities, blue and green. "Legitimacy becomes each group's appraisal of the other group's right to exist," Epstein explained. In this context, an agent's going activist means that it kills a member of the opposing ethnic group. The cops are peacekeepers, and if the model is run without them and L among all agents is reduced by as little as 20 percent, ethnic cleansing quickly begins. When cops are introduced, safe havens emerge. Nonetheless, interethnic hostility continues. Ultimately, as figure 2 shows and Epstein told me, "when you drop legitimacy in this variant, it always ends with one side wiping the other out." Cop density can be set at any level. "At low cop densities, you get rapid genocide. At high cop densities, you likewise can sometimes get rapid genocide, but also a highly variable outcome. On average, more cops makes it take longer." Enough longer to justify the expense of extra policing? It's all just highly uncertain, Epstein says; merely to have a surge of cops would not guarantee a good outcome.

Altogether, in fact, Epstein stressed that his models were mostly aimed at achieving explanatory power. "To explain something doesn't mean that you can predict it," he said. He pointed out that though we can explain lightning and earthquakes, we can't forecast either. If we're hoping, like Asimov, to predict the future, Epstein's models will disappoint. In fact, because his models give widely divergent results even when their agents are programmed with very simple rules, they indicate that predicting the future will never be possible. Still, Epstein's artificial societies do more to make plain the hidden mechanisms underlying social shifts—and their unexpected consequences—than any tool that social scientists have hitherto possessed. In the future, they and others like them could suggest how policymakers can engineer the sorts of small, cheap interventions that have large, beneficial results. TR

Mark Williams is a Technology Review *contributing editor.*



JASON SCHNEIDER

MEDICINE

Brain Boosters

Our reporter enters the new world of neuroenhancers by having his brain zapped with electricity and dosed with chemicals to see if it makes him smarter and more alert. **By David Ewing Duncan**

It's 2:00 P.M. on a Tuesday, and I'm feeling stupid and slightly grumpy. I have lingering jet lag because I took a trip to London last week and flew in last night from California. Now I'm sitting in the Brain Stimulation Unit of the National Institute of Neurological Disorders and Stroke in Bethesda, MD, with two electrodes affixed to my forehead. In a moment, a researcher in the lab of neurologist Eric Wassermann will activate a gizmo the size of a small clock radio, which will send an electric current through my frontal lobe, the part of the brain most associated with higher reasoning and emotion. For the next 40 minutes, the flow of electrons will create an electric field that lets neurons having to do with cognition and emotion fire more easily.

I'm here to investigate firsthand whether the latest brain gadgets and pills represent a new frontier in neuroenhancement. Wassermann has already told me that his device will not turn me into an Einstein. He is hoping that in people with brain injuries or impairments from disease, it will stimulate the cognitive centers to function better than they would otherwise. "We are starting with testing healthy people to get a baseline for how the technique works," he says.

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Two days from now I'm planning to further tweak my mind by taking a brain-boost pill. Called Provigil, it differs from its predecessors in that it is believed to home in on a section of the brain that helps govern alertness and memory. The pill is manufactured by Cephalon of Frazer, PA, and its active ingredient is called modafinil. The drug's targeted delivery is supposed to prevent the side effects of stimulants that diffuse throughout the brain and rev up everything. Provigil has been approved by the U.S. Food and Drug Administration for people who have excessive sleepiness associated with narcolepsy or otherwise disrupted sleep patterns—for example, from switching between shifts at work. In 2006, 2.6 million Provigil prescriptions were written. More than half of those were reportedly for off-label uses such as treating attention deficit disorder and depression.

In the Brain Stimulation Unit, a medical student turns on the juice under the watchful eye of Michael Koenigs, the postdoc running the experiment. I feel a slight tingle and an itch on my scalp as the current rises to 2.5 milliamps: a small amount, but enough to give a jolt. A couple of minutes later I have a metallic taste in my mouth. Koenigs warned me this might happen. Hundreds of people have been tested, and this is one of the few side effects they've reported.

In previous experiments on healthy people, Wassermann and others found that this procedure, called transcranial direct-current polarization, improved motor and cognitive performance. In one test, a direct current applied to the left frontal lobe boosted, by 20 percent, a person's ability to name as many words beginning with a certain letter as possible in 90 seconds. Wassermann's team is now testing electric fields with different charges against each other and against a sham, comparing subjects' responses through tests that measure cognition, memory, and emotions.

Direct current applied to the scalp polarizes underlying brain tissue, creating either a positive or a negative charge near the electrode. In vitro studies have shown that a weak current can substantially change the firing rate of neurons—with an increase or decrease in firing rate that depends on the orientation of the electric field. Evidence suggests that increases in firing enhance local brain function and decreases do the opposite.

Zapping brains is not new. In the 1960s, low-level direct current was used to treat mental disorders, but investigators became more interested in chemical treatments until recently, when neuroscientists and clinicians began looking for targeted brain boosters with fewer side effects than pills. Wassermann thinks that one day we will be able to buy a tiny device that can be inserted into a hat or attached to a headband and turned on when we need a brain boost.

My Brain, Altered

I feel a slight uptick, like a medium hit of caffeine; it gently lifts the fog of my fatigue, though I don't feel any smarter. I settle down to take some tests of cognition and emotion. Most telling is a gambling game that presents four virtual decks of facedown cards on a computer screen; when I click on them, cards turn over, and I either win money or lose it, depending on the card. A ticker measures my winnings at the top of the screen. At first the cards seem random, but then patterns develop: I need to figure out which stacks will yield more gains than losses, and vice versa. After a few minutes, my initial mild boost dissipates. I lose at the gambling game, though not by much. The next morning I return after a good night's sleep. Taking the gambling test sans stimulation, I win a modest amount of virtual cash.

Later that second day I participate in a third experiment. Instead of running a negative current through the electrodes attached to my forehead, as he did the first time, Koenigs applies a positive current. The effect on my frontal lobe causes a noticeable sense of relaxation and a drop-off in motivation as I play the gambling game. Oddly enough, I win big anyway. I also experience a strange sensation when I begin speaking to the researchers: I'm starting sentences and then losing my motivation to finish them. Koenigs says this is exactly what his experiment is trying to show: that performance is affected differently by different currents. I suspect my results have more to do with yesterday's exhaustion versus today's well-restedness, but the electricity has noticeably messed with my mind.

The day after that, I'm in New York City in the office of Steven Lamm, a physician who advocates the prescription of Provigil for patients with sleep disorders, persistent fatigue, or jet lag. "I would like to prescribe it more than I do," he says, "but because it has only been approved for severe sleep disorders, insurance doesn't cover the cost of the drug for many of my patients." Lamm has used Provigil himself when he is jet-lagged or short on sleep and needs to be sharp. "It is unhealthy to not get enough sleep," he tells me, "but sometimes it can't be helped." Lamm checks my blood pressure and takes a history, tells me about the drug, and scribbles out a prescription for five 200-milligram tabs.

Modafinil has been extensively studied as a treatment for sleep disorders, but data on its capacity for cognitive enhancement is thin. In Cambridge, England, researchers saw a spike in the short-term memory and planning ability of male volunteers who took the drug. Other researchers saw bone-tired subjects who took Provigil stay alert while using helicopter simulators; tests have also indicated that the drug can improve planning and the ability to remember long strings of numbers.

I swallow a pill at around 2:00 P.M., roughly the same time of day I was first tested in Eric Wassermann's lab. I'm walking down Fifth Avenue in the bright spring sunshine and feel nothing. I get a cell-phone call and start talking, feeling my usual afternoon dopiness. Later I board a flight back home to San Francisco, and about three hours after popping the pill, I fall asleep.

In San Francisco, I try Provigil again at 8:00 A.M., along with my usual cup of coffee. This time, after 15 or 20 minutes, I feel an alertness that caffeine alone doesn't usually give me; the feeling plateaus over the next three hours and resolves into a low-key but constant "up" sensation. I plunge into work and feel highly efficient and bright. For a little while, the sensation is almost too much, as if my brain has been set to fast-forward and can't be turned off.

That morning, I talk to Jeffry Vaught, the research and development chief at Cephalon. He tells me that the pill is a mild stimulant and does not prevent sleep if people desire it. "For people with narcolepsy," he says, "the impact is not mild; it's life changing." Vaught says the mechanism behind Provigil's effect is not well understood, but scientists know what part of the brain it involves. "It's a pathway involved with wakefulness, with waking you up and keeping you attentive," Vaught says. "This pathway is activated by modafinil." Major stimulants such as caffeine and amphetamines act on this part of the brain, too, but they also activate other regions, causing side effects such as jitters, loss of appetite, and that edgy feeling.

As the day wears on, my steady upness begins to get annoying. I'm calm, but I realize that when I write without the drug, I experience an intricate pattern of short ups interspersed with mild downs, during which I rest my brain. I'm not used to this uniform pharmaceutical lift.

Before long we might be drinking beverages laced with modafinil and other mild stimulants that have fewer side effects than coffee. It's likely that we'll also be slipping zappers onto the brims of our hats and flipping them on when we get spacey. But neither of these brain boosters is close to helping me, say, understand advanced quantum mechanics or write a symphony like Mozart. I'll have to muddle along being me for a bit longer. TR

David Ewing Duncan is a Technology Review *contributing editor. His next book is* Experimental Man: A Molecular Autobiography.

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Holographic Video for Your Home

A compact optical setup that produces 3-D video could make holography cheap enough for many consumer applications.

By Kate Greene

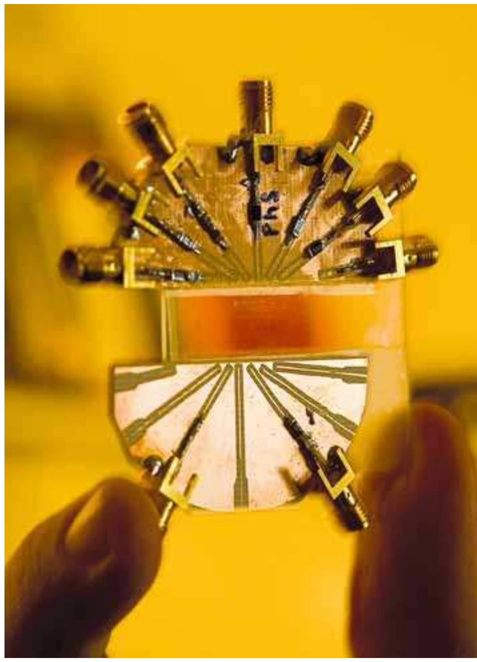
In a dark room down the hall from Michael Bove's office at MIT's Media Lab is an apparatus with a white screen the size of a CD jewel box. When Bove sits in a chair opposite the machine and flips a switch, an image of a human rib cage seems to leap out a few inches beyond the screen. The image is produced by the Mark II, a 14-year-old holographic-video system that takes up most of the room. But its vividness is one of the inspirations for Bove's own project: to bring 3-D video displays to consumer and medical markets.

Bove's new system, which is called Mark III, is scheduled to be completed by the end of the summer. It can run on a standard PC with a graphics card and will be small enough to fit on top of a desk. (In contrast, an earlier version of Mark II required whole racks of computers.) Although Bove doesn't yet have any manufacturing partners, he predicts that a product based on Mark III's design would cost just a couple of hundred dollars to manufacture and could become standard in doctor's offices as a way to view magnetic resonance images and computed tomography scans in 3-D detail. It would also be within the price range of gamers and technology enthusiasts.

The development of holographic video at MIT dates back to the late 1980s, when researchers put together Mark I, a proof-of-concept system with a low-resolution display. But Mark I and Mark II were destined never to leave the lab. They were, Bove says, "loud, finicky, and a general pain in the neck to work with." And while numerous researchers in the United States, Japan, Korea, and the United Kingdom have invested time and money in holographic video, no one has yet found a way to build a system that is compact, inexpensive, and easy to use.

In 2004, Bove, who is the head of the Consumer Electronics Lab at MIT, started exploring the possibility of making holographic video practical for con-

PHOTOGRAPHS BY PORTER GIFFORD



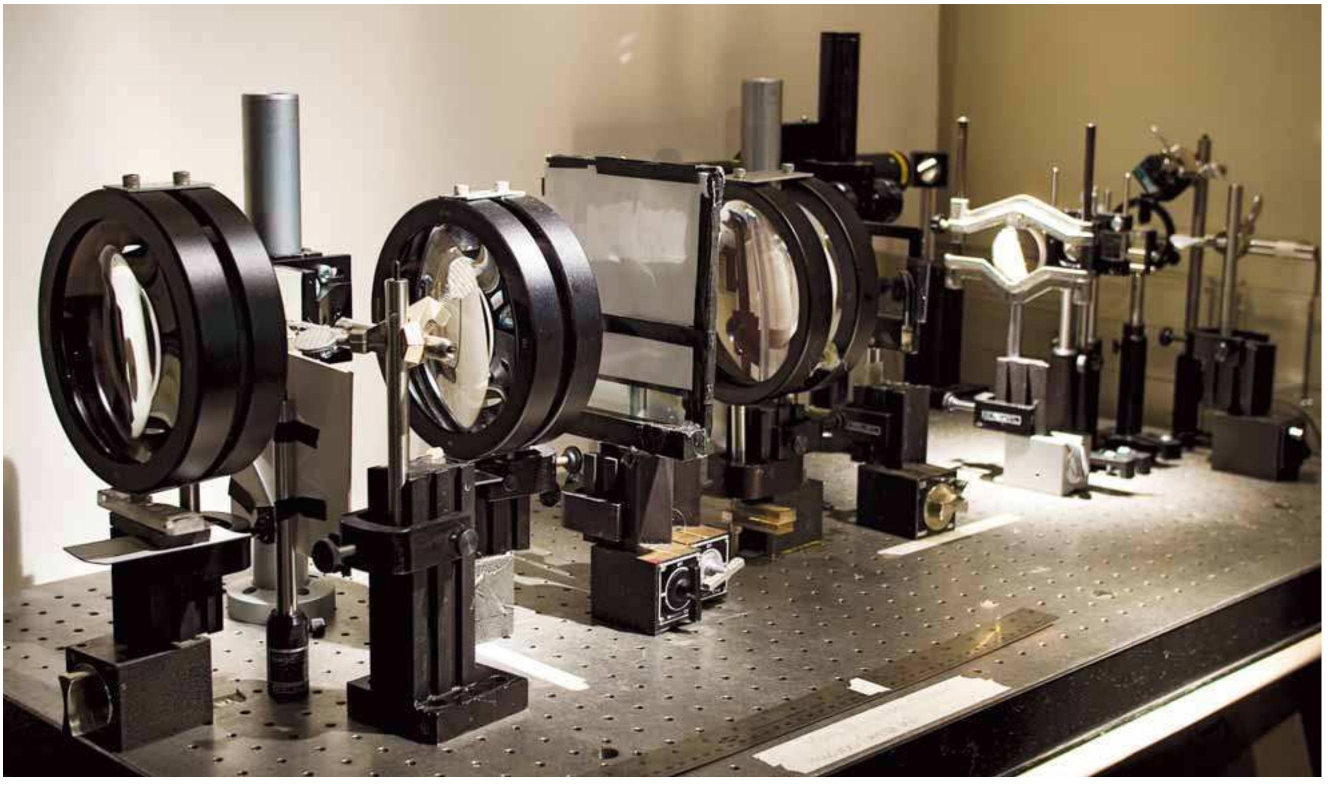
ILLUMINATING IMAGES **Michael Bove holds a hologram of a teacup (opposite). Bove's team has developed a high-bandwidth, multichannel light modulator (above) that converts a one-gigahertz electrical signal into a holographic video. The signal makes the clear crystal in the center of the device vibrate at specific frequencies. When laser light shines into the crystal (left), the vibrations change the directions and intensities of the emitted light, creating diffraction patterns—the basis of a hologram.**

sumers. Thanks to ever-more-powerful PCs, small, ultrabright lasers, and other compact optoelectronic devices, he says, a consumer-friendly system is now within reach. And, he says, "there's more and more 3-D information that's kicking around" and could easily be projected holographically. Many video games, for example, are now based on sophisticated 3-D models of the virtual world—models that have to be flattened out for the 2-D screens of PCs or game machines. Similarly, the 3-D data in hospitals' large stores of magnetic resonance images and computed tomography scans has to be rendered as 2-D cross sections in order for doctors and patients to interpret it.

The Media Lab's video holograms appear to float above a piece of frosted glass. An electronic device behind the glass, called a light modulator, reproduces interference patterns that encode information about the pictured object. Laser light striking the modulator scatters just as it would if it were reflecting off the object at different angles.

A holographic video begins with a computed 3-D model of some moving object or scene. This model "can be thought of as having a whole lot of points on its surface at different depths that change over time," Bove says. To make that model holographic, a computer needs to figure out the intensity of the light that would be reflected from each point on the object to the point where the viewer's eyes will be. "You need to create a diffraction pattern that reconstructs all the different intensities for all the different angles," Bove says. He found that graphics chips in today's PCs are adept at doing this sort of 3-D rendering, computing the diffraction patterns, and combining them into a single video output.

After the computation is complete, the output is fed to the light modulator. The introduction of a novel modulator, says Bove, is a primary reason he and



LENS CRAFTING **An earlier holographic-video system (left) required racks of equipment to drive the modulators and moving mirrors. A new modulator decreases the number of optical components needed (above). The optics of Mark III will eventually fit into a box half a meter long.**

his team have been able to shrink the holographic setup. The modulator is an inexpensive device adapted from use in telecommunications; Daniel Smalley, a graduate student in Bove's lab, modified its components, optimizing them to convert electrical signals into holographic patterns. Previous holographic systems used up to 18 separate modulators that were made of expensive materials and took up a lot of space. The new device, says Bove, is about half the size of a postage stamp. It's fast and can accommodate a large amount of data, allowing for high-resolution holograms.

When light from a laser or set of lasers enters the modulator, it's converted into a series of diffraction patterns that are shaped and focused by a number of lenses and mirrors before they reach the screen. One of the advantages of the new modulator, explains Bove, is that it allows the researchers to avoid using a bulky rotating mirror that previous setups required to keep a holographic scene from drifting horizontally. That mirror was "the bane of the two early generations of [holographic] video display," he says. Now that it's been eliminated, Quinn Smithwick, a postdoc in the lab, has figured out how to shorten and fold the system's optical path so that the necessary components fit into a space about half a meter long.

Currently, Mark III uses a gas laser housed in a foot-long tube. But in its final version, it will use a semiconductor laser as small as a postage stamp. Bove says the system will project a monochromatic video scene, about the size of a snapshot photo, that will have the resolution of a standard television image.

Aware that this sort of display wouldn't cut it in consumer applications, Bove and his team have laid out plans for the next generation of the system, Mark IV. Mark IV will use a set of powerful red, blue, and green semiconductor lasers to shine full-color videos onto a screen the size of a computer monitor. A prototype could be ready within the next couple of years.

The market, of course, will dictate how quickly, if ever, holographic video makes its way into living rooms or doctor's offices. If all goes well, however, it could give doctors a better window into the body, let scientists visualize data more accurately, and help gamers immerse themselves more deeply in virtual worlds. TR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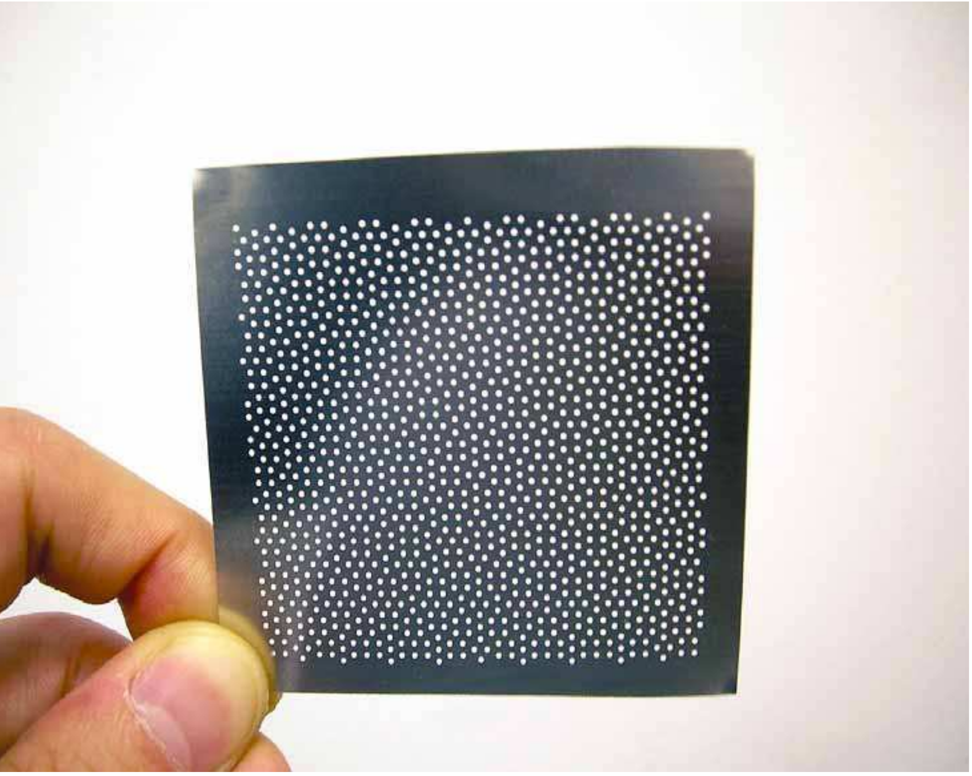


The spacing between the holes in this metal film determines the wavelength of terahertz radiation that passes through.

TATSUNOSUKE MATSUI, UNIVERSITY OF UTAH

INFORMATION TECHNOLOGY

Filtering Terahertz Frequencies

A new type of filter could make extremely fast wireless communication devices possible

SOURCE: **"Transmission Resonances through Aperiodic Arrays of Subwavelength Apertures"**
Tatsunosuke Matsui et al.
Nature 446: 517–521

RESULTS: Researchers at the University of Utah have designed a perforated stainless-steel film that restricts the frequencies of terahertz radiation passing through it. In effect, the film is a simple terahertz filter, a potential precursor to terahertz communication devices.

WHY IT MATTERS: The filter could provide a way to control terahertz radiation in future wireless devices. Though still years from commercialization, wireless networks that use this radiation—which technically ranges from about 100 gigahertz to 10 terahertz—could carry much more data than existing networks, speeding up wireless Internet links by a factor of a thousand. Terahertz transmission would be most useful for relatively short-range communication—between devices in a room, for example.

METHODS: The new filter is made of stainless steel with arrays of holes in it. When terahertz radiation passes through the holes, it propagates as a terahertz wave with a few narrow frequency bands; the frequencies emitted depend on the spacing of the holes. Where previous studies had assumed that uniform arrays were necessary for terahertz filtration, the Utah researchers used irregular arrays of perforations, allowing several different frequencies of radiation to pass through the filter at the same time.

NEXT STEPS: The researchers will now try to build terahertz communication devices based on the principles demonstrated by their work thus far.

Touch Screens That Vibrate

A touch screen that offers tactile feedback could help people type more accurately on PDAs

SOURCE: **"Tactile Feedback for Mobile Interactions"**
Stephen Brewster et al.
CHI 2007, April 28–May 3, 2007, San Jose, CA

RESULTS: Researchers at the University of Glasgow, Scotland, have found that mobile phones and PDAs whose touch screens vibrate when touched promote better typing and are easier to use than nonvibrating devices. In the lab, subjects made 22 percent fewer typing errors and were able to correct 48 percent more of their errors when they used vibrating PDAs. Those benefits diminished somewhat when subjects were tested on a moving train.

WHY IT MATTERS: More and more phones are being designed to let users enter numbers and letters using touch screens. But virtual buttons on a flat

display simply don't feel like buttons, and people using them are prone to errors. Some researchers suspect that adding tactile cues—such as vibrations when a screen is touched—will improve the interface.

METHODS: To the backs of several PDAs, the researchers attached actuators that caused the gadgets to vibrate when their touch screens were tapped. The vibration was smooth when a subject pressed a button correctly but rougher if the subject made a mistake, such as tapping a button twice. Twelve study participants, who had never used PDAs before, were given poems to type into the devices as accurately and quickly as possible, both in the lab and on a moving train.

NEXT STEPS: The group is exploring additional ways of using actuators in mobile devices. For example, actuators at the four corners of a device could denote the progress of a file download: the actuators would vibrate in sequence until the download was complete.

BIOTECHNOLOGY

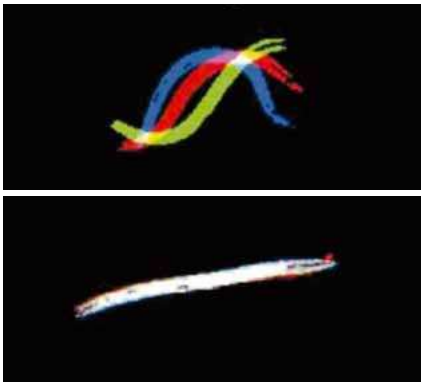
A Light Switch for the Brain

A light-triggered switch to control brain cells could aid in the development of therapies for depression, Parkinson's, epilepsy, and other neurological diseases

SOURCES: "Multimodal Fast Optical Interrogation of Neural Circuitry"
Feng Zhang et al.
Nature 446: 633–639

"Multiple-Color Optical Activation, Silencing, and Desynchronization of Neural Activity, with Single-Spike Temporal Resolution"
Xue Han and Edward S. Boyden
PLoS One, March 21, 2007

RESULTS: Scientists at MIT and Stanford University have independently created a light-controlled molecular switch that can turn off electrical activity in neurons. By combining it with a similar, previously developed switch that can trigger electrical activity, neuroscientists can now use light to turn specific neural circuits on and off.



A light-activated switch can control the movement of a microscopic worm. The top image shows a worm genetically engineered to carry the switch. The overlapping images illustrate the animal's movement. In the bottom image, the worm is exposed to light, which paralyzes its muscles.

WHY IT MATTERS: The new neural switch enables unprecedented control over the brain and could lead to more-effective therapies for epilepsy, Parkinson's, depression, and other brain diseases. The neural switch could also serve as a research tool to help neuroscientists decipher the language of the brain—the information, encoded in the electrical activity of neurons, that forms our memories and directs our every move.

METHODS: To create the new neural switch, researchers borrowed a gene from a lake-dwelling microörganism; the gene codes for a light-sensitive protein that pumps chloride ions. One study showed that the chloride-ion pump can be genetically engineered into specific neurons in the brain or into muscle cells. When one of these genetically modified cells is hit with yellow light, the pump brings a negative charge into it, preventing it from firing.

NEXT STEPS: The scientists are now using the two switches in animals genetically engineered to model epilepsy, depression, and Parkinson's disease. The hope is to find neural cells whose activity or inactivity is responsible for symptoms characteristic of those diseases, including seizures in epilepsy. Such findings could aid in the development of drugs targeted to only those cells; one day, light-activated implants might replace the electrodes used in treatments such as deep brain stimulation.

Universal Blood

Researchers have found a way to efficiently convert different human blood types into a neutral type that can be given to any patient

SOURCE: "Bacterial Glycosidases for the Production of Universal Red Blood Cells"
Qiyong Liu et al.
Nature Biotechnology 25: 454–464

RESULTS: An international team of researchers has created universal blood cells—blood that can be given to people of any blood type. The researchers developed the universal blood by using enzymes to remove the cell-surface sugars that determine whether blood is type A, B, O, or AB. These sugars can trigger immune reactions in people whose blood cells don't share them.

WHY IT MATTERS: In emergencies, doctors often have to give patients blood transfusions without knowing their blood type. So emergency medical workers must use type O, which is universally compatible but often in short supply. The new technology could make any donor's blood universally compatible.

METHODS: The researchers screened different enzymes for their ability to efficiently cleave off the complex sugars on the surfaces of red blood cells. They identified two bacterial enzymes that cleave only A- or B-type sugars, leaving other sugars on the blood cells' surfaces intact.

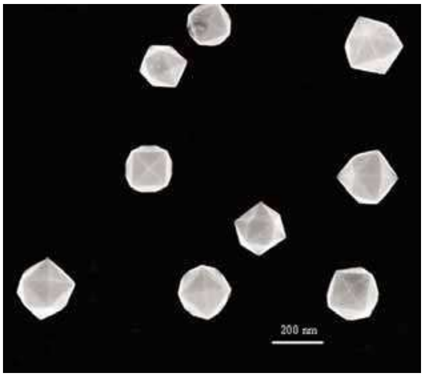
NEXT STEPS: Blood processed using the sugar-cleaving enzymes is currently in early phase II clinical trials in the United States. ZymeQuest, a startup based in Beverly, MA, that is commercializing the universal-blood technology, has developed a machine that uses the enzymes to process blood quickly. The company expects that if all goes well, its blood-processing machines will be on the market in Europe in 2011 and in the United States a few years later.

NANOTECHNOLOGY

Better Catalysts

Multifaceted platinum nanoparticles may help explain catalysis and could lead to cheaper fuel cells and alternative fuels

SOURCE: "Synthesis of Tetrahexahedral Platinum Nanocrystals with High-Index Facets and High Electro-Oxidation Activity"
Na Tian et al.
Science 316: 732–735



The many angles and edges of the 24-sided platinum nanoparticles shown in this micrograph increase the catalytic activity on their surfaces.

XIANG ZHANG, GEORGIA TECH

RESULTS: Researchers at the Georgia Institute of Technology in Atlanta and at Xiamen University in China have made platinum nanoparticles with a new 24-sided shape. The surfaces of the nanoparticles have four times as much catalytic activity as the surfaces of commercial catalysts. This is because of the greater number of unstable atoms at the particles' edges and the odd angles of the shape's many facets.

WHY IT MATTERS: Platinum is a common component of industrial catalysts. It's also used in fuel cells and in experimental methods for producing alternative fuels. But it's expensive, so researchers are constantly looking for ways to use less of it by making catalysts more active. The new shape and the methods used to make it could also help reveal how catalysts work in general, providing hints for researchers attempting to make better catalysts from cheaper materials.

METHODS: The Georgia Tech and Xiamen researchers began with platinum particles scattered on a carbon surface. They then applied an oscillating voltage to the surface, inducing alternating chemical reactions that broke down the platinum particles, releasing platinum atoms. The voltage also influences how the atoms recombine to form new particles. For example, when a positive voltage is applied, oxygen atoms can infiltrate the growing nanoparticles, dislodging platinum atoms from certain areas but not from others. This is the process the researchers exploited to create the 24-sided shape. (The same process also causes a layer of platinum oxide to form on other parts of the nanoparticles, protecting them.)

NEXT STEPS: The new platinum nanoparticles, which are 50 to 200 nanometers in diameter, are still at least 10 times the size of the particles now used in commercial catalysts, so they have a larger proportion of expensive platinum locked beneath their surfaces, where it can't catalyze reactions. As a result, though the new nanoparticles are better catalysts by area, they are, for now, worse by volume, the key parameter when it comes to cost. The researchers are now modifying their fabrication process to produce smaller nanoparticles that still have the novel shape.

Larger OLED Displays

Nanostructured metals could replace expensive and brittle oxide-based transparent electrode materials for use in displays

SOURCE: "Nanoimprinted Semi-transparent Metal Electrodes and Their Application in Organic Light-Emitting Diodes"
Myung-Gyu Kang and L. Jay Guo
Advanced Materials online, April 13, 2007

RESULTS: University of Michigan researchers have made flexible grids of copper, gold, and aluminum that are almost transparent, so thin and distantly spaced are their wires. The wires are 120 or 200 nanometers wide and separated by gaps of about 500 nanometers in one direction and 10 micrometers in the other. Used as electrodes, the grids outperformed the indium tin oxide (ITO) electrodes commonly used in displays and photovoltaics.

WHY IT MATTERS: The grids could be particularly useful for organic light-emitting diodes (OLEDs), which make displays that are bright, efficient, and potentially flexible. OLEDs are now limited to use in small displays, such as those in mobile phones. ITO is too brittle for use in larger flexible displays. The metal grids are not brittle and have better electrical properties than ITO.

METHODS: The researchers used a technique called nanoimprint lithography to achieve the precise wire width and spacing necessary for the grids, testing different wire configurations for their transparency and their electronic properties. They also tested a prototype OLED that used a copper-grid electrode instead of an ITO one.

NEXT STEPS: The proportions of the wires are being optimized to help the grids compete with other potential replacements for ITO, such as films made of carbon nanotubes. TR

Web 0.1

Before the Internet, there was videotex.

By Michael Patrick Gibson

The Web is filled with immersive virtual geographies *(see "Second Earth," p. 38)*. Eventually, they could merge into what's been called the "Metaverse," a 3-D virtual world in which real economies, social networks, and educational resources flourish.

Homes wired for data services were easy to predict 22 years ago; the interactivity of network users was not. In October 1985, *Technology Review* published "The Inevitable March of Videotex," in which Ralph Lowenstein, then dean of the University of Florida College of Journalism and Communications, and Helen Aller, then director of the college's Electronic Text Center, described a recent technology: for an initial payment and monthly fees, subscribers received a "decoder" that translated data into a format readable on their TVs and a terminal that let them retrieve information from a central computer. The success of such "videotex" systems in Europe, where services were state sponsored, had impressed U.S. media conglomerates. In the early 1980s, the service seemed poised to find a place in U.S. homes.

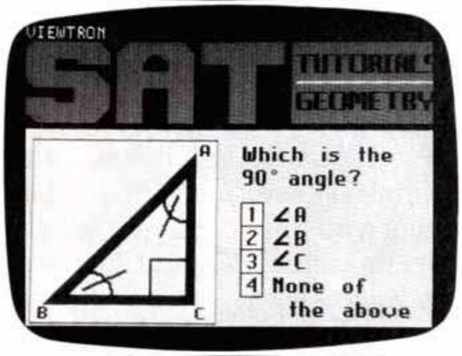
By 1985, a few U.S. companies had lost millions on videotex. Two notable letdowns were Keyfax, a joint venture of the *Chicago Sun-Times*, Honeywell, and the telecommunications company Centel that found a few hundred subscribers in Chicago, and Viewtron, a Knight-Ridder–AT&T project delivered to fewer than 3,000 in Florida. For prospective customers, the combined cost of equipment, phone usage, and the service itself proved prohibitive. Knight-Ridder did, however, find some success when it began offering videotex for personal computers.

Whereas the Internet was designed to be decentralized and by the mid-1980s was operated by a host of entities, videotex relied on communication with a single media service: users had no choice of content beyond that offered by their service providers. Yet the vision spelled out for videotex is oddly familiar. Lowenstein and Aller argued that the two-way transmission of text and graphics would hollow out traditional news media and facilitate the exchange of information, goods, and services.

Screens feature many colors, and the content includes news from several wire services, auctions of products ranging from golf balls to yachts, lessons in Spanish and Scholastic Aptitude Tests, weather bulletins, stock-market quotations, home banking services, airline schedules, and hundreds of special subjects. But the move to personal computers may limit the technology's expansion. For while almost everyone owns at least one color television set, only about 18 percent of American homes have personal computers—and most of those computers are not equipped with the modems necessary to receive videotex services. …

What will the videotex era be like? Just imagine the advantages of having immediate access to books, magazines, major newspapers, and reference works from any library or publishing house in the world. Children will be able to retrieve a few pages from a continually updated encyclopedia, with their parents paying royalty costs only on those pages selected. It will be possible to read—and pay for—just the first 10 pages of a sorry novel; the author might still come out ahead, because thousands more people might want to "test-read" the novel than would buy the printed version. Videotex subscribers will also be able to buy stocks, send messages home, make plane reservations, and receive simple medical diagnoses. …

The advantage of a system that can bring a world of knowledge into every home or business puts the apparent disadvantages into a shadow. A truly free society—as opposed to an authoritarian one—depends on the availability to the average citizen of a wide variety of news and political information. This will be the case in the videotex era



Videotex services presaged what would come later with the Internet.

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